ARCHITECTURE DEPARTMENT

MASTER OF ARCHITECTURE PROGRAMME

CHINESE UNIVERSITY OF HONG KONG

2008-2009

DESIGN REPORT

WORKING WITH NATURE:
A PROTOTYPE FOR AN ECOLOGICAL HIGH-RISE OFFICE BUILDING IN HONG KONG

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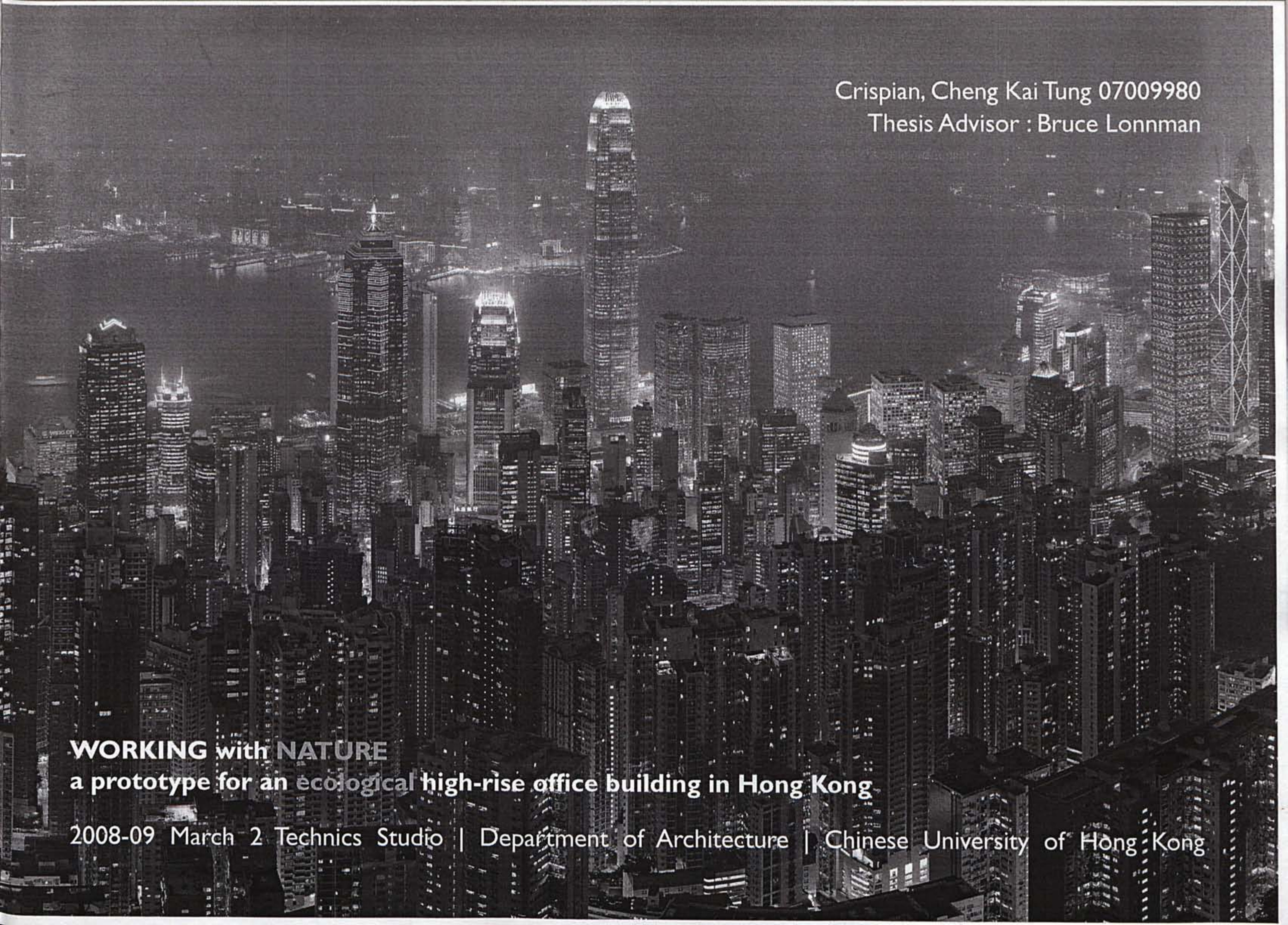
May 2009



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WORKING with NATURE

a prototype for an ecological high-rise office building in Hong Kong

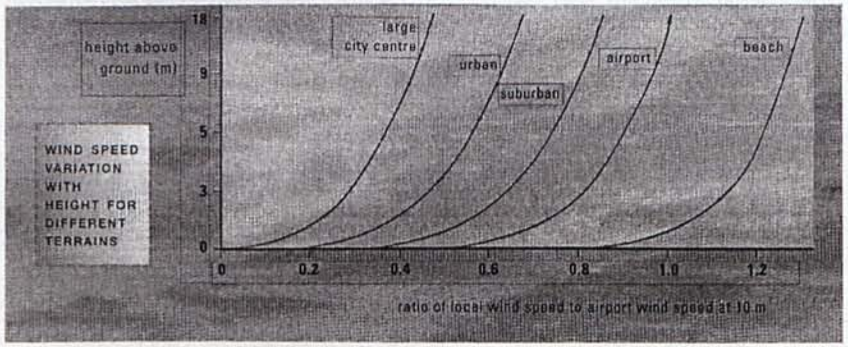
2008-09 March 2 Technics Studio | Department of Architecture | Chinese University of Hong Kong

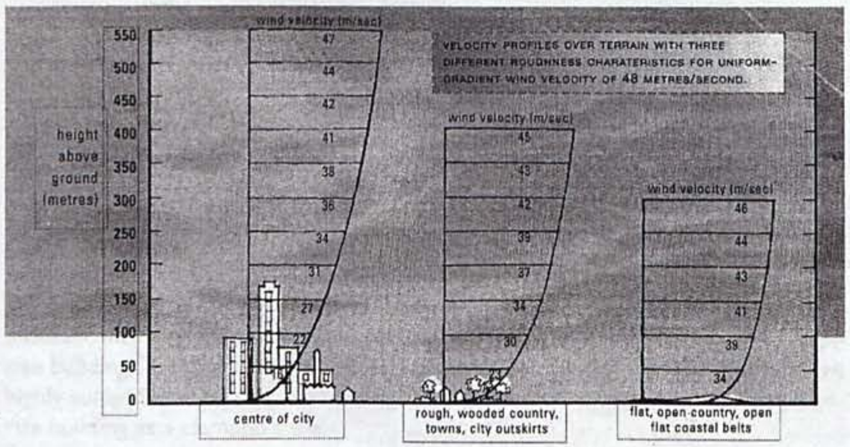
ABOUT WIND - I

FORMATION OF WIND PROFILE

As the wind strikes a building, its shape and gradient are affected by the climatic conditions of the geographical area, the surrounding terrain, and the effects of other buildings adjacent to the building.

The terrain starts influencing the wind several miles upwind from the building site and creates a wind profile, which describes the shape and the gradient of the wind, including turbulence, gusts and eddies in the boundary layer.





BOUNDARY LAYER

In physics and fluid mechanics, a boundary layer is the layer of fluid in the immediate vicinity of a bounding surface. In the Earth's atmosphere, the planetary boundary layer is a layer of air sometimes hundreds of metres above the ground affected by diurnal heat, moisture or momentum transfer to or from the surface. It separates laminar flow from uniform flow.

All air above the boundary layer is moving in uniform flow and is unaffected by the roughness or character of the ground surface terrain. Air within the boundary layer is in laminar flow and contains turbulence, gusts and eddies. Laminar flow increases with altitude as it approaches the limit of the boundary layer.

LAMINAR FLOW

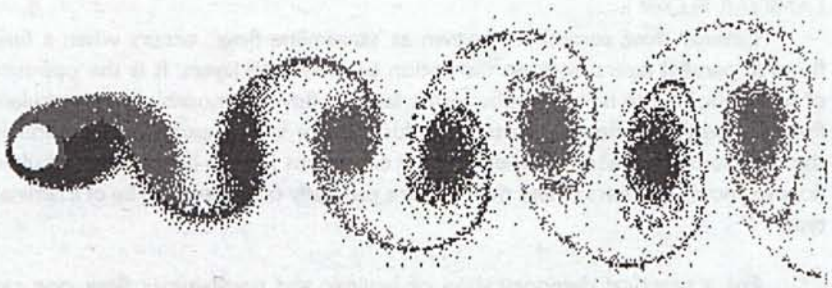
Laminar flow, sometimes known as 'streamline flow', occurs when a fluid flows in parallel layers, with no disruption between the layers. It is the opposite of turbulent flow. In non-scientific terms, laminar flow is 'smooth', while turbulent flow is 'rough'. The dimensionless Reynolds number is an important parameter in the equations that describe whether flow conditions lead to laminar or turbulent flow. Reynolds numbers of less than 500 are generally considered to be of a laminar type.

For a practical demonstration of laminar and non-laminar flow, one can observe the smoke rising off a cigarette in a place where there is no breeze. The smoke from the cigarette will rise vertically and smoothly for some distance (laminar flow) and then will start undulating into a turbulent, non-laminar flow.

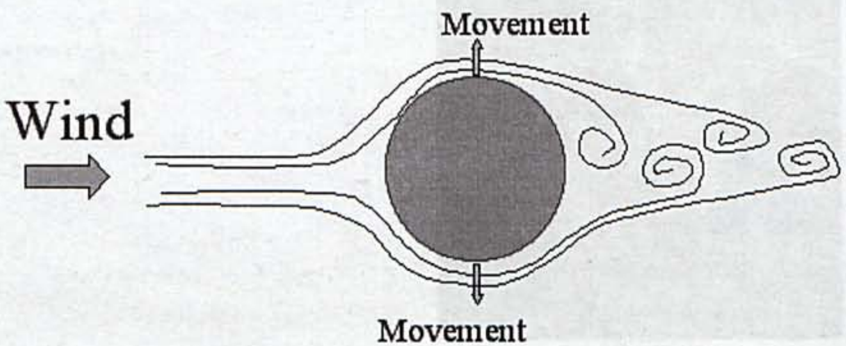
ABOUT WIND - II

VORTEX SHEDDING

Depending on the size and shape of the building, steady wind velocity can cause vortex shedding in the wake of the structure. Vortex shedding is an unsteady flow that takes place in special flow velocities according to the size and shape of the building (especially for a cylindrical building). In this flow, vortices are created at the back of the body and detach periodically from either side of the body.



Vortex shedding is caused when a fluid flows past a blunt object (like a cylinder). The fluid flow past the object creates alternating low-pressure vortices on the downstream side of the object. The object will tend to move toward the low-pressure zone.



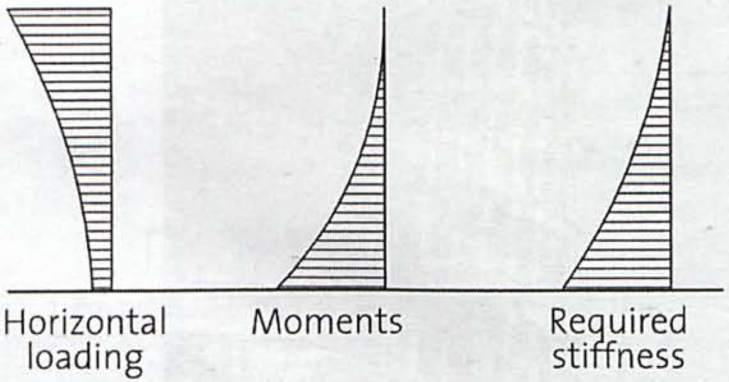
Eventually, if the frequency of vortex shedding matches the resonance frequency of the structure, the structure will begin to resonate and the structure's movement can become self-sustaining. Tall chimneys constructed of thin-walled steel tube can be sufficiently flexible that, in air flow with a speed in the critical range, vortex shedding can drive the chimney into violent oscillations that can damage or destroy the chimney. These chimneys can be protected from this phenomenon by installing a series of fences at the top and running down the exterior of the chimney for approximately 20% of its length. The fences are usually located in a helical pattern. The fences prevent strong vortex shedding with low separation frequencies.

SPECIAL FEATURES OF HIGH-RISE STRUCTURES

The fact that high-rise structures are taller than low-rise structures implies higher vertical loads and, more importantly, higher lateral loads (mainly due to wind stress) in high-rise structures. Both of these influences on design are so significant that special demands are placed on the high-rise structures.

LATERAL LOAD IN HIGH-RISE STRUCTURES

The behavior of a high-rise structural system under lateral loading is comparable to a cantilever fixed into the subsoil. Assuming under a uniform lateral load, the fixed-end moment on the cantilever increases quadratically with the height. In reality the horizontal loads are not constant over the height, but increase. Thus the moment towards the base increases more rapidly.



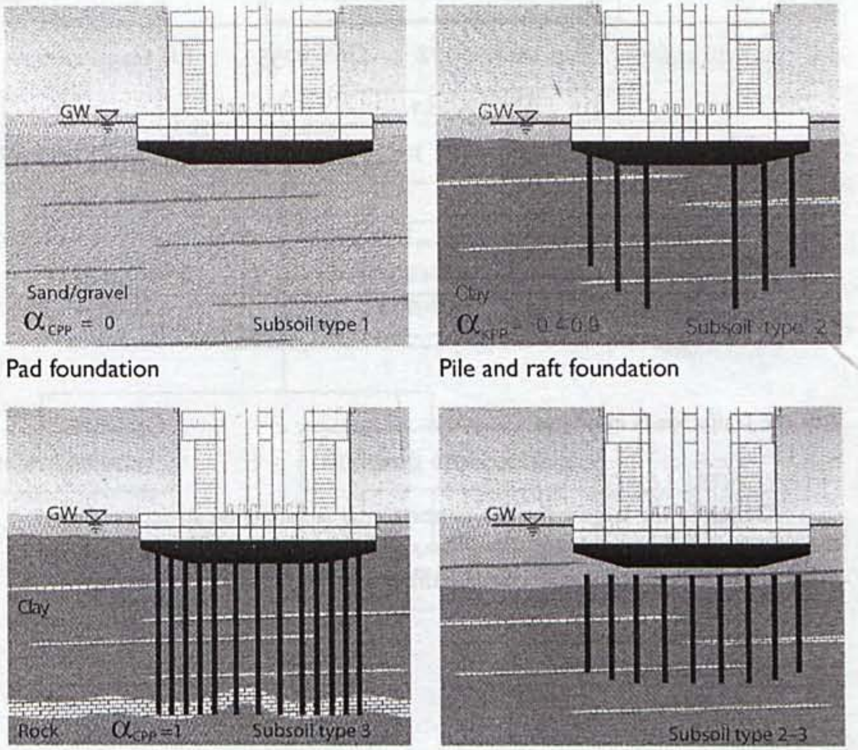
ABOVE Behavior of high-rise structure under lateral loading

TRANSFER OF LATERAL LOAD TO FOUNDATION

The absorption of horizontal loads and the ability to transmit the resulting moment into the foundation is a primary task in the structural design of high-rise buildings. Existing stairwell cores with their continuous vertical elements are highly suited for removing the loading. Another option is to treat the entire high-rise building as a clamped tube.

With the coupling of forces, the moment can be effectively transferred. However, this causes tensile stresses in the vertical elements, which can only be tolerated in exceptional cases in reinforced concrete constructions. Therefore an attempt is made to distribute the dead loads (mainly the flooring) in such a way that the tensile stresses resulting from horizontal loads are continually compressed or overcompensated. Thus the system of horizontal load removal affects the distribution and transfer of the vertical loads.

It should be noted that the height at which lateral loads become dominant for multistory buildings in independent of the definition of a high-rise as set down by the building code. A regulation that buildings are high-rise when the height of the top floor exceeds 22m reflects the size of fire-service ladders rather than structural considerations. The question at what height in regard to statics one can refer to high-rise buildings cannot be answered. Even for buildings under 22m the removal of lateral loads can be decisive in the design. Such is the case when the existing core and shear walls are unable to secure lateral stability.



ABOVE Foundation options

LOADS ON HIGH-RISE STRUCTURES

VERTICAL LOADS

The theory of vertical loading for high-rise buildings is identical to that of lower buildings. Dead loads arise from the weight of the individual construction elements and the finishing loads. Live loads are dependent on use. For normal office use in high-rise buildings live loads should be taken to vary between 2.0 and 5.0 kN/m². Flooring in premium office space is now usually constructed to withstand live loading of 5.0 kN/m², taking into account variable partitioning and higher live loads in the corridor areas. Depending on the number of stories, live loads can be reduced for load transfer and the dimensioning of vertical load-bearing elements. However, the reduction of the total live load on a construction element may not exceed 40 percent.

	USA -1972 ANSI A58.1 [kN/m²]	DIN 1055 [kN/m²]	EC 1 [kN/m²]
Office space	2.40	2.00	3.00
Lobbies	4.80	5.00	5.00

ABOVE Traffic loads in offices

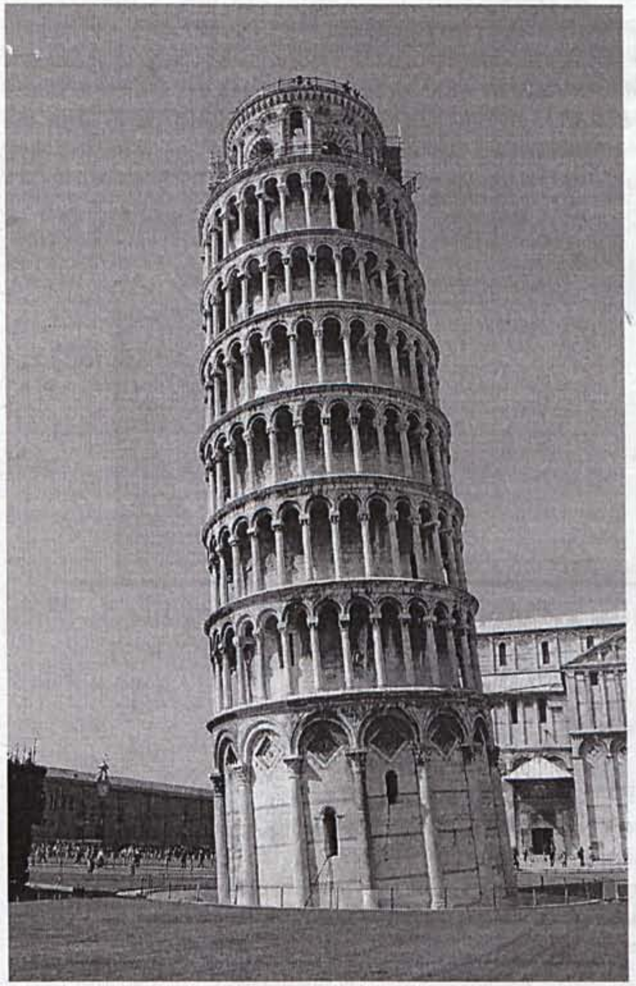
HORIZONTAL LOADS

Owing to the large influence of horizontal stiffening on structure design, the calculation of lateral loads should be carefully scrutinized. The lateral loads generally arise from:

1. Unexpected deflections
2. Earthquake loads
3. Wind loads

UNEXPECTED DEFLECTIONS

Unexpected deflections arise from imperfection in the manufacture of construction elements and larger components. In addition to this manufacturing problem the uneven settling of the foundation at an inhomogeneous site can also lead to a deflection. Any deflection produces additional lateral forces which must be incorporated into the design.

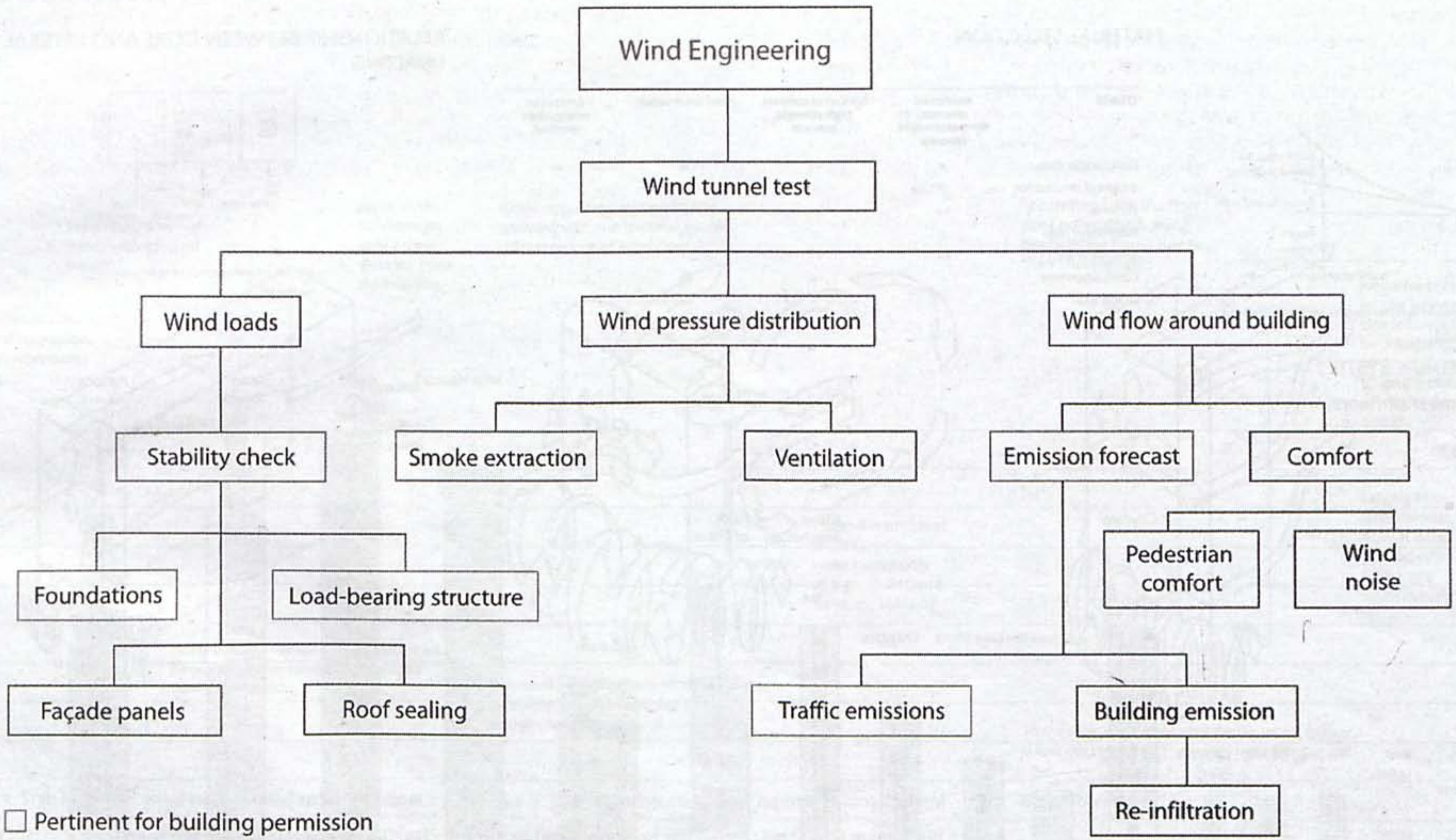


ABOVE The leaning tower of Pisa

EARTHQUAKE LOADS

Since Hong Kong is not located in areas susceptible to earthquake activity, lateral loads caused by earthquake are neglected.

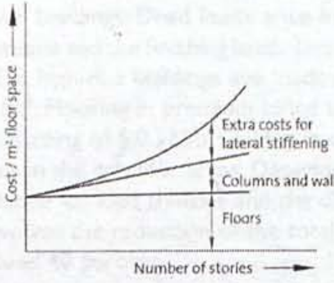
EFFECTS OF WIND ON HIGH-RISE



Schematic presentation of areas covered by wind engineering

CONSIDERATIONS OF HIGH-RISE LOAD BEARING STRUCTURE

COST

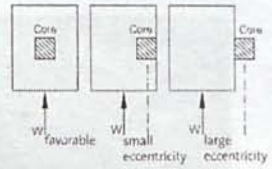


Breakdown of costs for vertical and horizontal load removal [9]

MATERIAL SELECTION

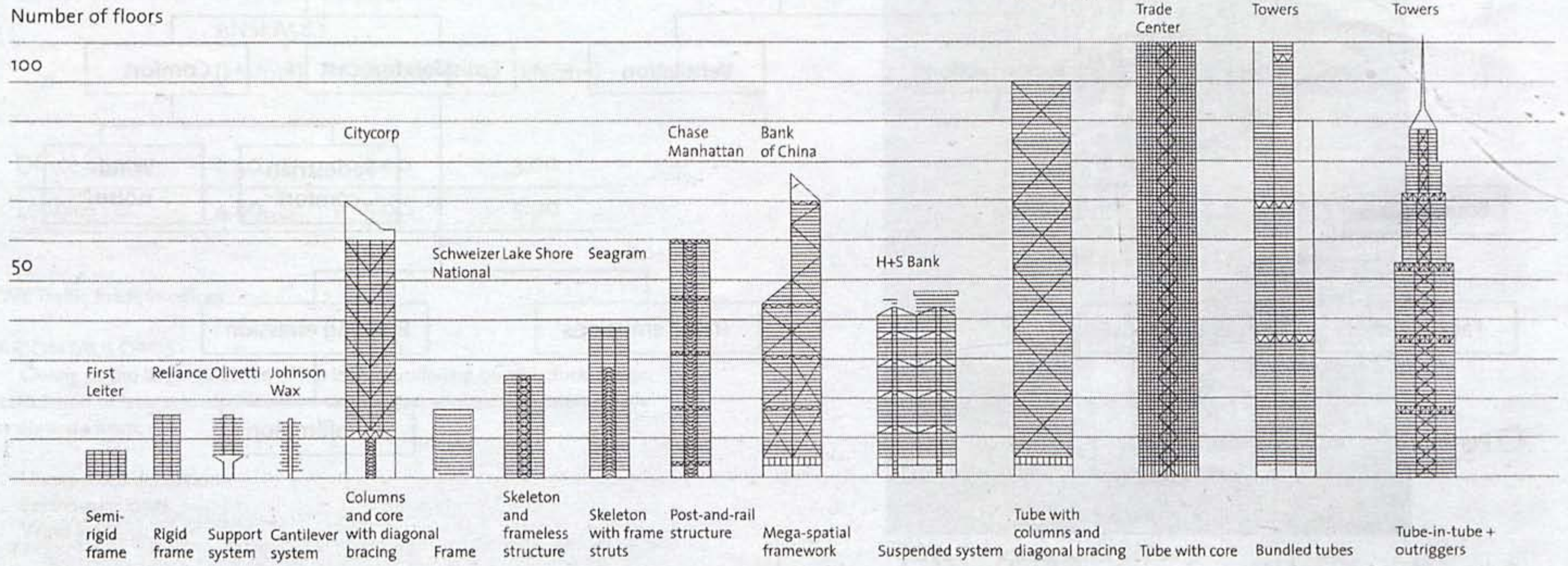
Criteria	Reinforced concrete, Normal-strenght concrete	Reinforced concrete, High-strenght concrete	Steel construction	Composite construction method
Construction costs	+	++	o	++
Weight of construction	o	+	++	+
Stiffness	++	++	o	+
Flexibility of plan	o	o	++	+
Behavior in fire	++	++	–	+
Construction time	+	+	++	++
Usable area	–	+	++	+

RELATIONSHIP BETWEEN CORE AND LATERAL LOADING



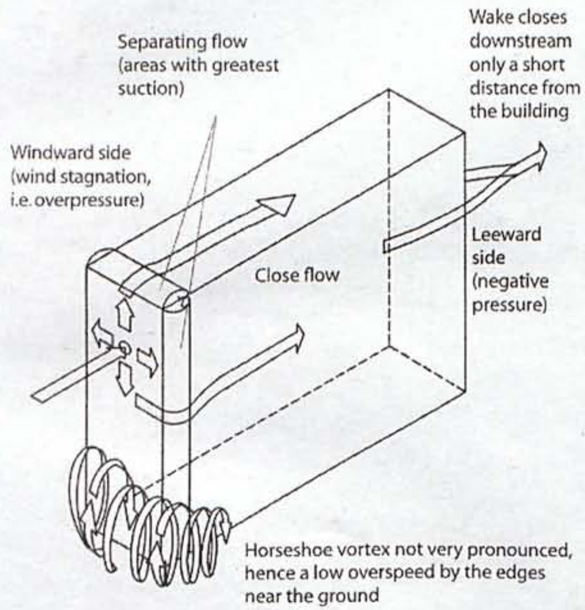
6.10 Influence of core positioning on horizontal loading [9]

STRUCTURAL SYSTEM

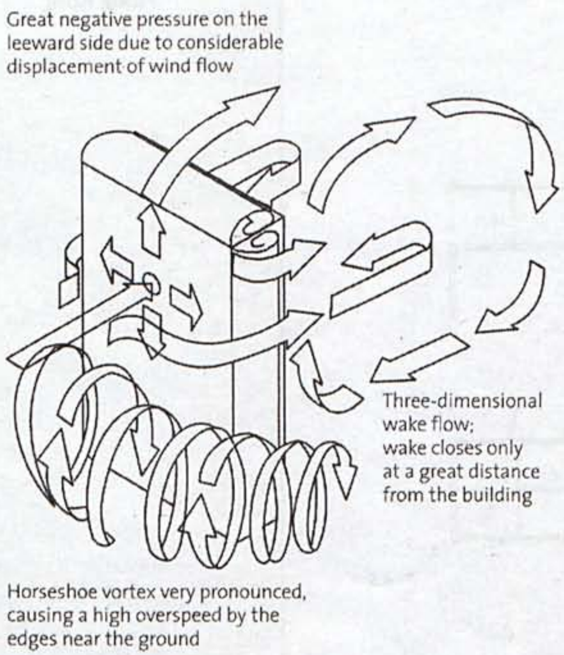


Matrix: load-bearing structures of towers

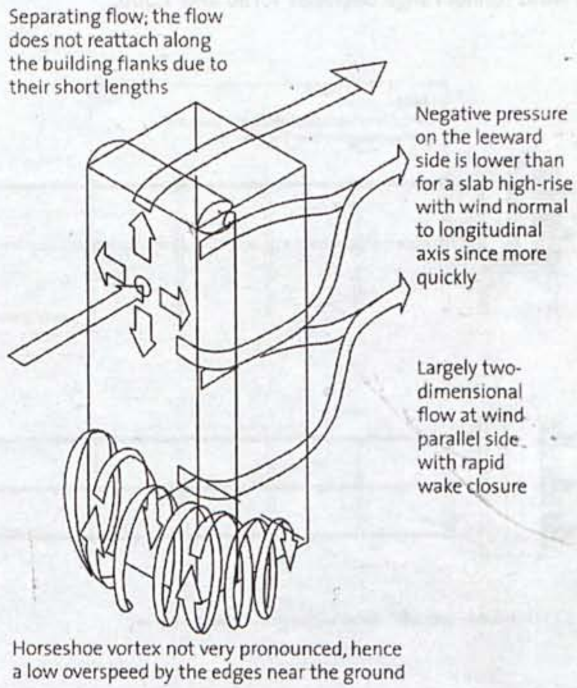
WIND FIELD - WIND PRESSURE DISTRIBUTION
BASIC UNDERSTANDING



9.2 a Slab high-rise, wind flow parallel to longitudinal axis (narrow windward side results in lower air displacement)



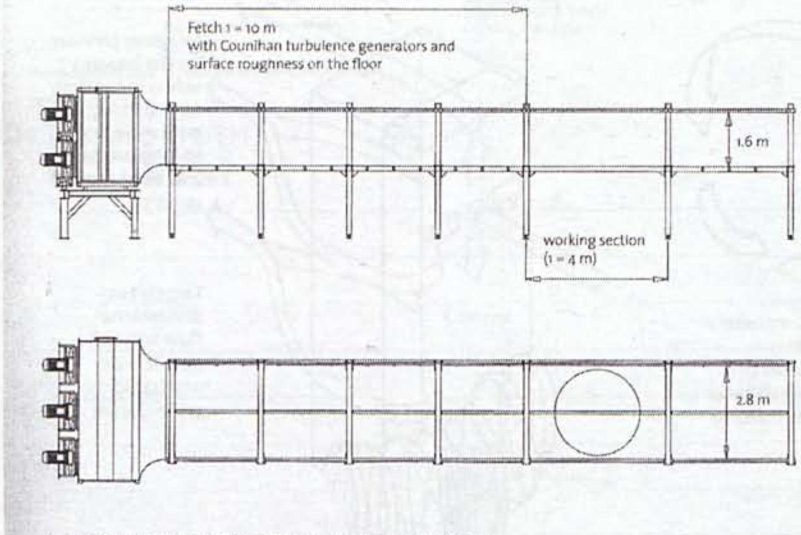
9.2 b Slab high-rise, wind flow normal to longitudinal axis (great width of windward side results in large air displacement).



9.2 c Tower

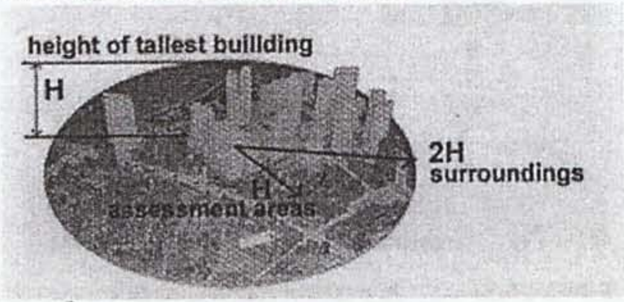
WIND TUNNELS

Defining the wind pressure distribution on buildings in boundary layer wind tunnels has become the national and international standard. The atmospheric wind flow is a turbulent layer, which can be expressed through the increase of the velocity with height (velocity profile) and through turbulence (turbulence intensity profile and spectral distribution of velocity energy). The typical model scales for this wind tunnel range between 1:150 and 1:500.



9.4 I.F.I. boundary layer wind tunnel: section (above) and plan (below)

AIR VENTILATION ASSESSMENT, 2003



PAPER STUDY

COMFORT TEMPERATURES FOR NATURALLY VENTILATED BUILDINGS IN HONG KONG

CONCLUSION

Indoor natural ventilation to airspeed of about 1.0 - 1.5 m/s would satisfy the thermal comfort requirement of 80% of occupants under hot summer period in Hong Kong

ISSUE 1
HEALTH VENTILATION

RWE HEADQUARTERS

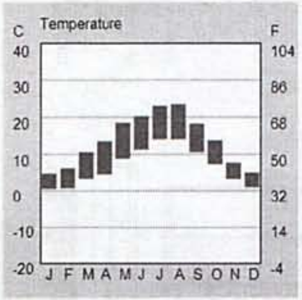
ARCHITECT
Ingenhoven Overdiek und Partner

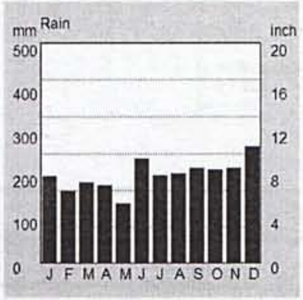
YEAR OF COMPLETION
1996

LOCATION
Essen, Germany

CLIMATE IN ESSEN

Essen is located in the northwestern part of Germany and has an oceanic climate with rainfalls all year round. Winters are relatively mild and summers tend to be comparatively cool, even though temperatures can reach above 28°C for prolonged periods of time.





LEFT
Temperature chart of Essen

RIGHT
Rainfall chart of Essen

LEFT
Location of Essen

BUILDING FORM

SHAPE OF THE BUILDING

A cylinder 32m in diameter sits above one garden level

NUMBER OF STOREY

34

ANY TAPERING TOWARDS THE TOP

None

HEIGHT OF THE BUILDING

Facade	120m
Elevator tower	127m
Aerial tip	162m

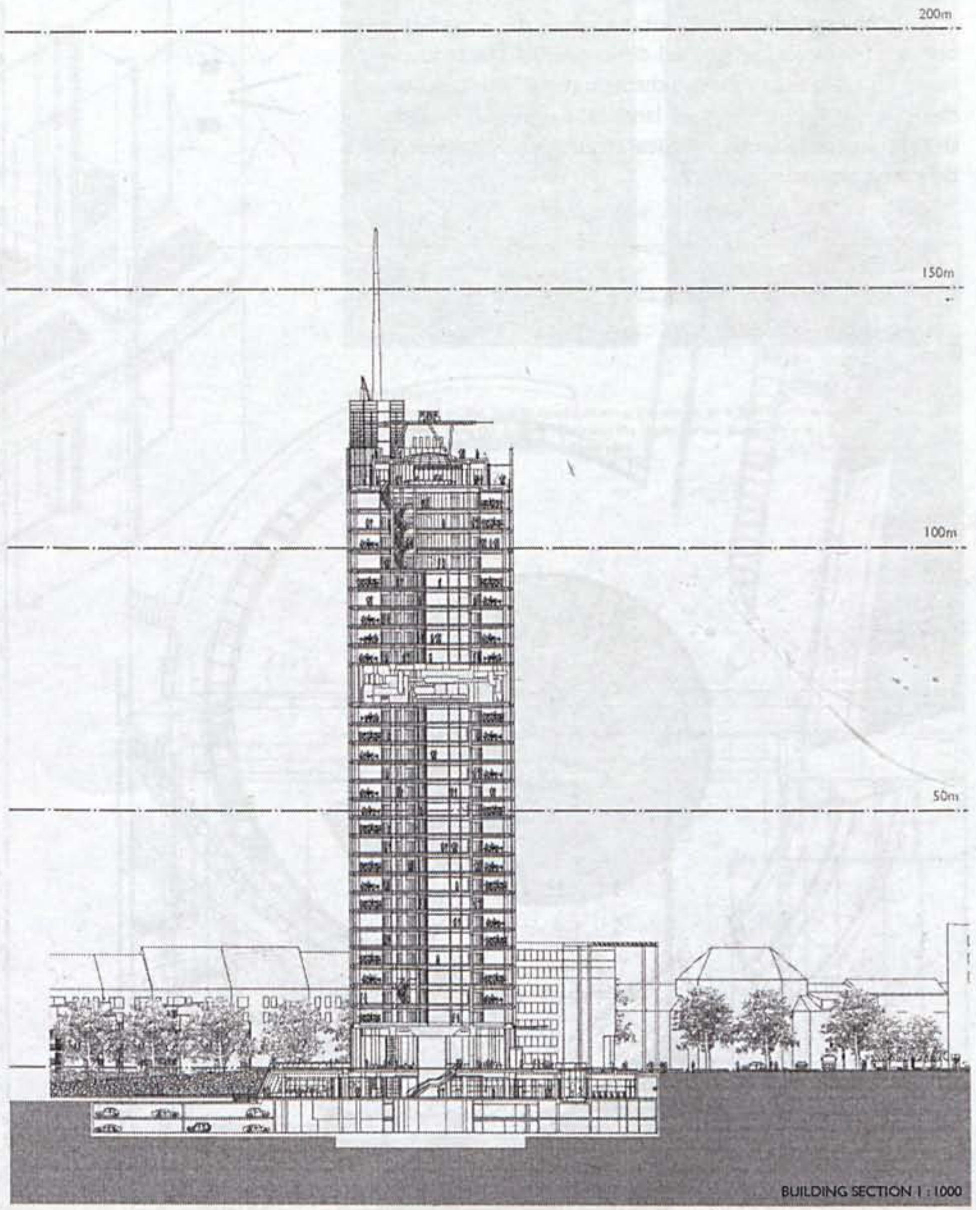
WIDTH OF THE BUILDING

Tower	32m

WIDTH TO HEIGHT RATIO

1 :3.75

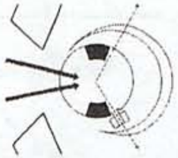
LEFT
Aerial photograph of the RWE headquarters

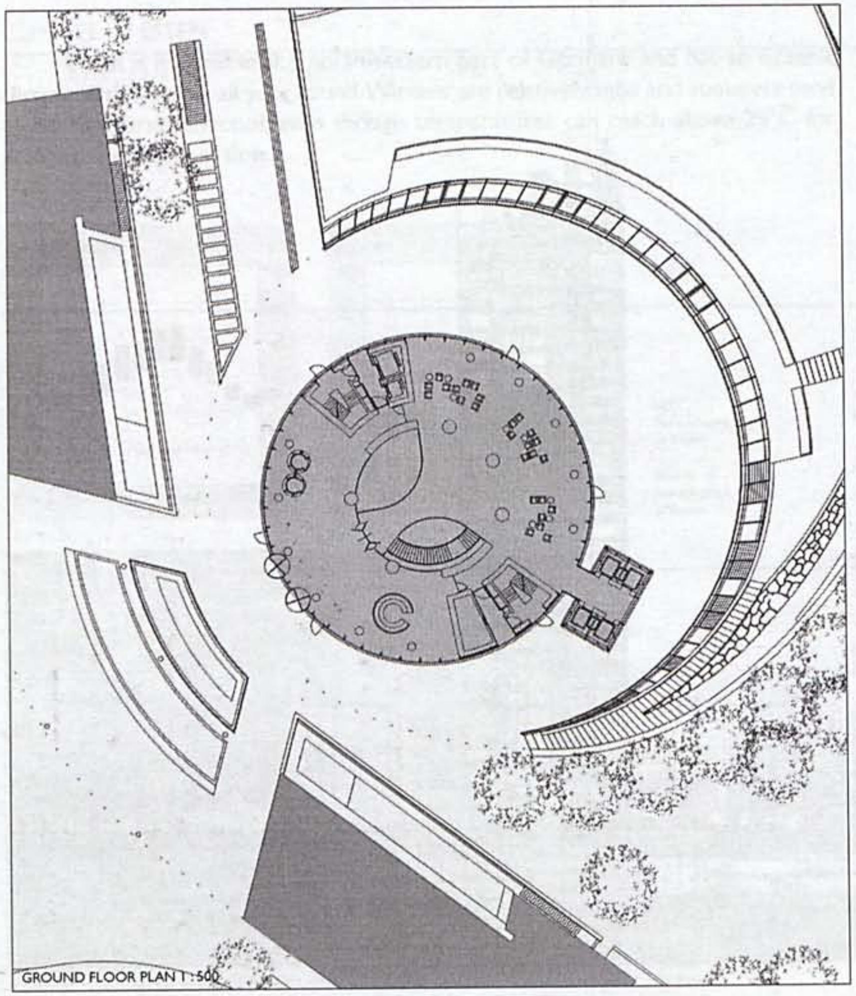


BUILDING INTERIOR

LOCATION OF SERVICE CORE

The service cores are located along the edge, not at the centre, thus revealing the full dimension of the space in the lobby. This lets the eye travel through the glass lobby towards the exterior - a park, whose landscape was also designed by the architects. The main vertical circulation is provided by a detached elevator tower.

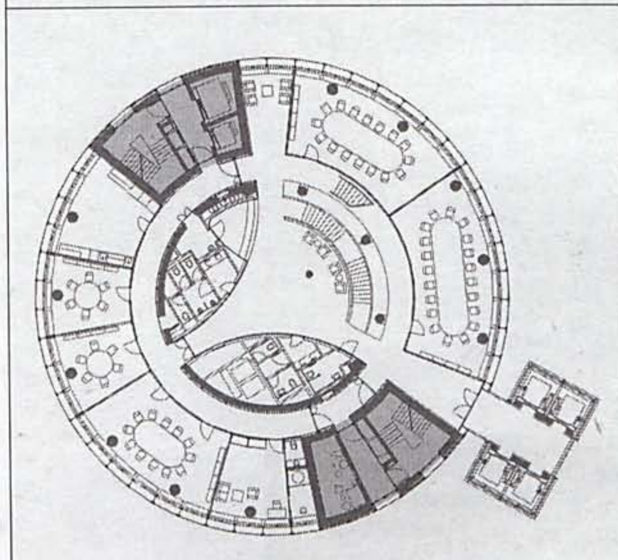


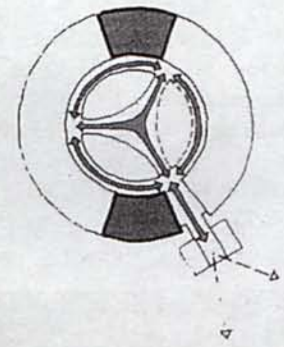


GROUND FLOOR PLAN 1 : 500

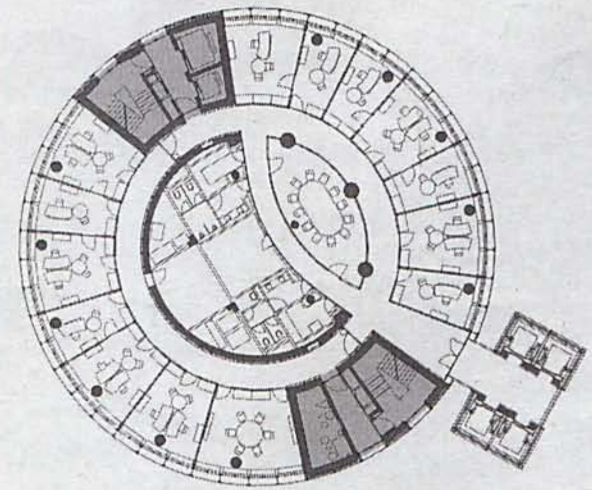
FLOOR PLAN SHOWING SERVICE CORES AND OTHER STRUCTURE ELEMENTS

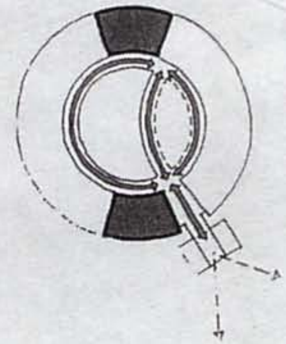
CIRCULATION AND VIEW DIAGRAM





CONFERENCE LEVEL PLAN 1 : 350





TYPICAL FLOOR PLAN 1 : 350

APPROX. EFFICIENCY : 60%

BUILDING ENVELOPE

FACADE SYSTEM

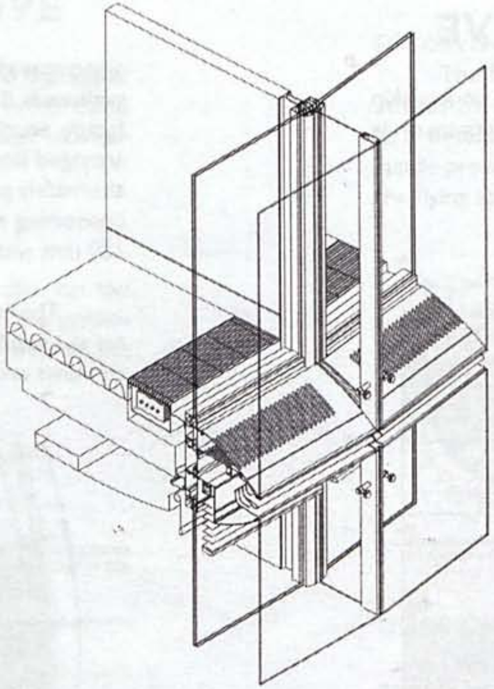
Double-skin facade system

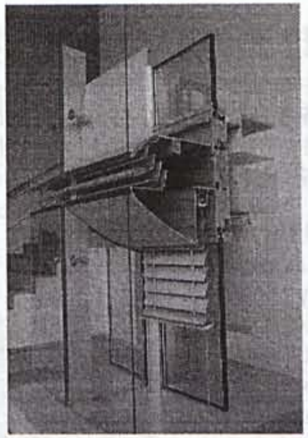
MAJOR FUNCTIONS OF FACADE SYSTEM

1 To allow natural ventilation when external conditions are appropriate

2 To protect the occupants from under exposure to sunlight

3 To allow optimum use of daylight therefore the glazings are as transparent as possible



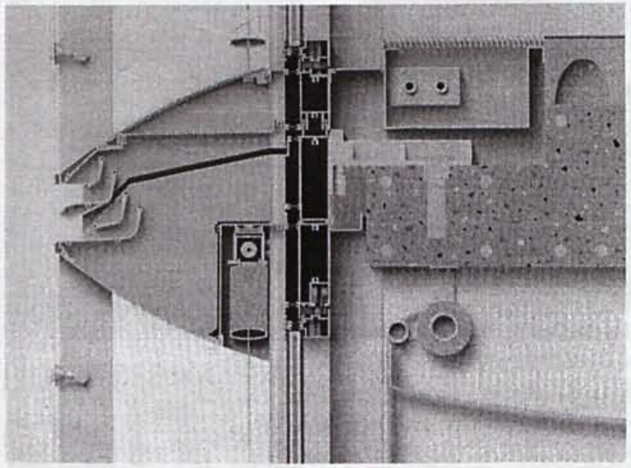


ABOVE LEFT
Full-scale model of the double facade showing the details of a fish mouth and other environmental controls, viewed from the outside. Note that the upper curved aluminium sheet is in its raised position thus exposing the flat maintenance walkway plate.

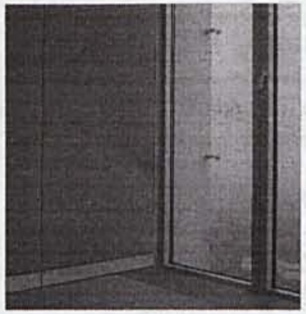
ABOVE RIGHT
Installation of a facade unit

LEFT
Isometric view of the facade

BELOW
Section of a typical office space

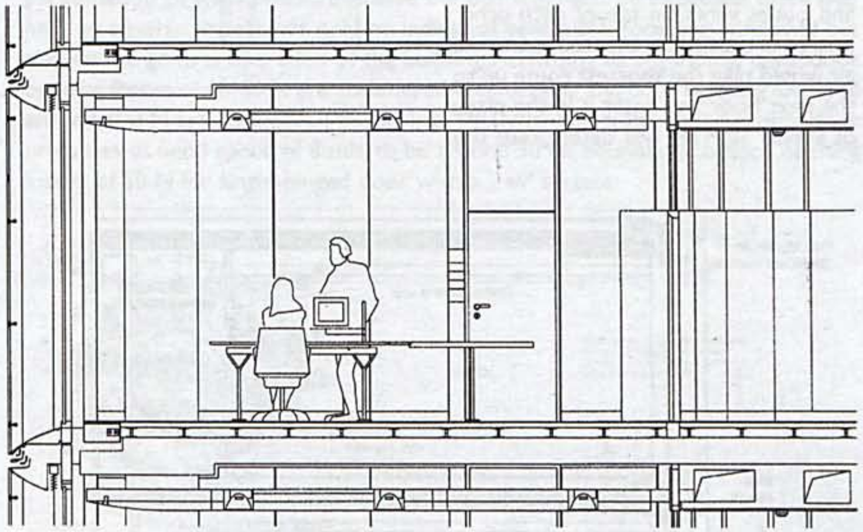


LEFT
The 'fish mouth' mullion which allows for a controlled flow of natural ventilation



LEFT
Sun protector blinds inside the double layer facade

RIGHT
Clear glazing for optimum use of daylight



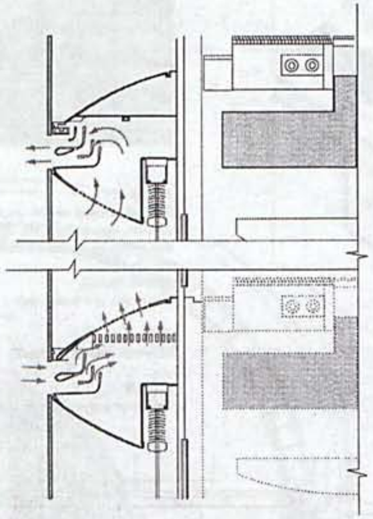
STOREY HEIGHT OF TYPICAL OFFICE SPACE : 3.60M

NATURAL VENTILATION - PASSIVE

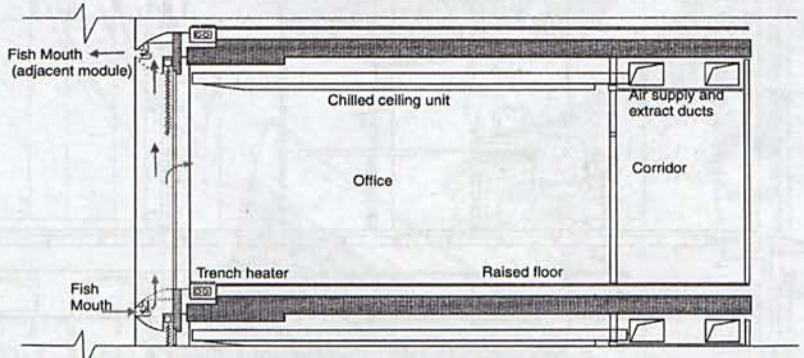
OUTER LAYER - FISH MOUTH MULLION

Passive natural ventilation is achieved via the fish mouths of the double-skin façade. The fish mouths are designed to act either as low-level air inlets to, or as high-level air outlets from, the double façade space.

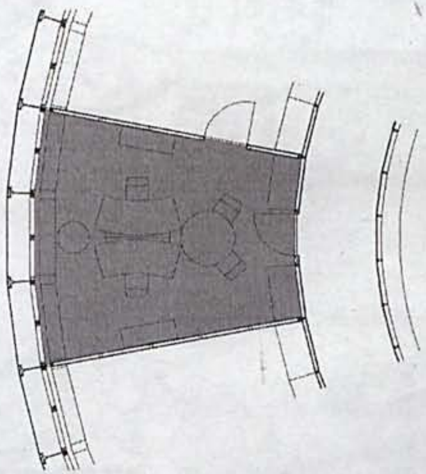
In practice, the fish mouths at the bottom of one glazing panel act as inlets to the façade space immediately above, while those at the top of the adjacent panel act as outlets from that façade space. A double set of curved aluminum sheets is immediately behind each fish mouth, the upper one hinged, the lower fixed. The upper sheet is perforated if its fish mouth is to act as an air inlet; if it is to function as an air outlet, then the lower sheet is perforated.

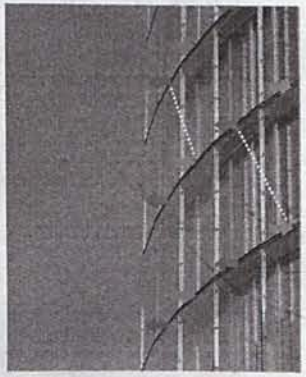


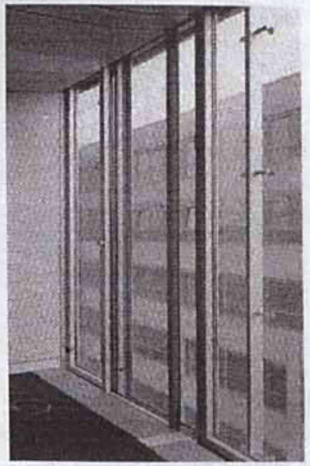
Even the smallest office would have at least two glazed panels – thus enabling the air to 'meander' through its double façade. An arrangement of in- and outlet vents on top of each other proved unacceptable because extracted air would take the shortest route up to the next floor and enter it in the place of supply air. This will deteriorate the air-temperature in the façade corridor and air quality generally would deteriorate with each floor. The simple solution lies in creating diagonal air streams in the facade corridor, it would require the supply and extracted air sections to be arranged laterally, i.e. next to each other. As mentioned above, this is achieved by alternately perforating the under and upper sides of the double-panelled platforms connecting the inner and outer glass walls. An effective section is achieved with 120 mm wide vents.



The limited outer supply air vents and the perforation of the platform panels act as a wind-breaker to on-coming wind, thus preventing disruptive draught when windows are opened, even at considerable heights.







INNER LAYER - SLIDING WINDOW

The inner layer of the double-skin façade is comprised of full-height, handwheel-operated sliding windows, one per bay, which can be wound open sideways up to 155 mm in normal use for ventilation, of fully open for window cleaning.

ABOVE LEFT
An office unit with three glazed panels

ABOVE RIGHT
Alternating pattern of perforated and non-perforated aluminium sheets at the tops of the glazed panels

RIGHT
Full height, handwheel-operated sliding windows

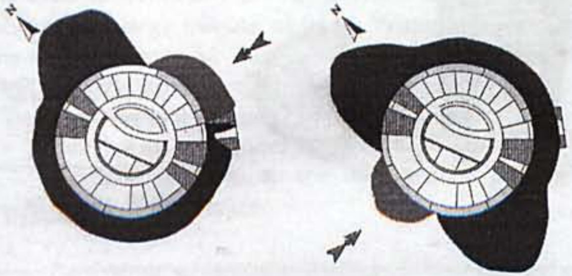
NATURAL VENTILATION - PASSIVE

WIND CONDITIONS ON SITE

In Essen, south to westerly winds prevail. Wind speeds around the upper floors of the building are, taking the building's height and its location within Essen into account, still 30-40 % higher than wind speeds around the local weather station.

WIND FORCES EXERTED ONTO THE BUILDING, AERODYNAMICS OF THE BUILDING

The following graphs illustrate the different pressure dispersion on the external layer of the building for different oncoming wind directions. Strong suction peaks, caused by the air flow around cylindrical buildings are clearly visible on the charts.



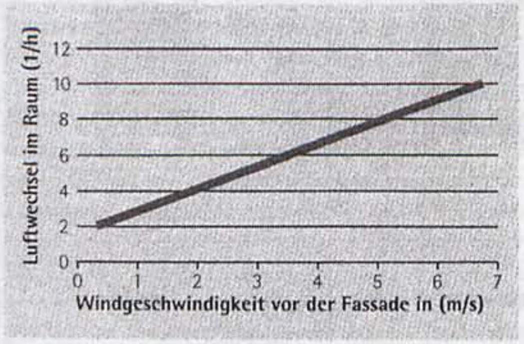
Qualitative pressure distribution on the external shell at high winds

LEFT Approx. wind pressures, easterly winds

RIGHT Approx. wind pressures, westerly winds

NATURAL VENTILATION OF ALL FLOORS

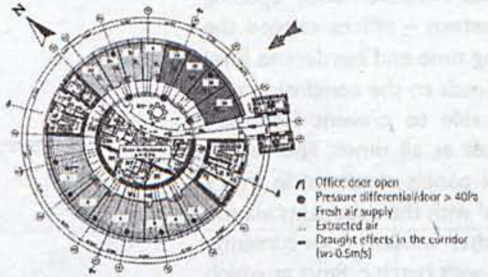
The double-layer façade offers the advantage of limited dynamic wind impact on the offices. Measurements at the façade test site have shown a reasonable air change rate produced by the perpetually changing wind pressures. The possibilities offered by the double-layered façade with regards to a minimization of cross-ventilation and door-opening forces were examined.



LEFT
Diagram shows the recorded hourly air exchange rates inside the offices (maximum rates) in the case of individual office ventilation and in relation to ambient air speeds (in front of facade).

CROSS VENTILATION

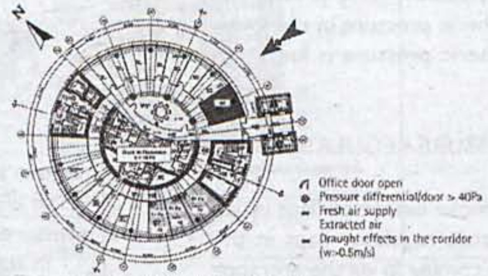
The following graph shows the typical ventilation throughout the building at medium wind speeds with opened windows and doors in the offices and up to a 40-fold air change rate; As mentioned previously, the slits in the double-layer façade provide sufficient reduction of cross-ventilation and effectively help prevent the flying about of loose paper.



Air exchange at medium wind speeds (4m/s)

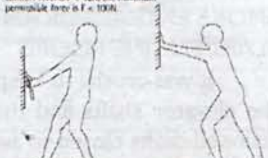
DOOR OPENING FORCES

Not only cross-ventilation but also the occurrence of increased door opening forces and increased forces exerted on partition walls, both caused by the perpetuation of wind pressures inside the building, must be expected; these may have an adverse impact not only on individual ventilation (opening windows) but also on the general operation of the building. According to ergonomic tests, door opening forces of 40-60 N are considered comfortable and door opening forces of around 100 N are considered borderline. The following graph shows typical door pressures, at wind speed of 8 m/s, to be around 50 Pa, equivalent to door opening forces of 50 N for single-hinged door with a 2 m² surface.



Pressure on doors at high wind speeds (8m/s)

Door opening forces: draught forces (left) and pressure forces (right). The mean comfort level is F < 40N, the maximum permissible force is F < 100N.



NATURAL VENTILATION - PASSIVE

OPERATIONAL LIMITATIONS FOR WINDOW-VENTILATION

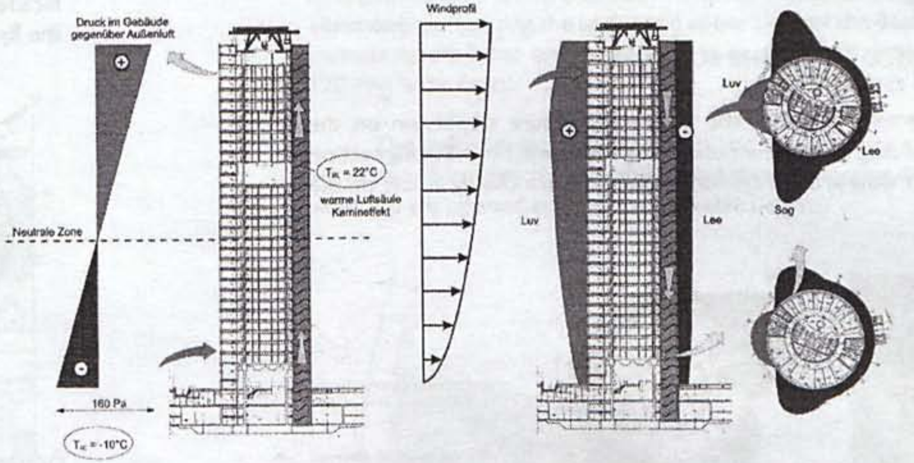
During c. 30-40% of operating time the air change rate is more than 25-fold, a point at which closing the office doors is recommended. A c. 200-fold air change, when loose paper would be expected to fly about in a building with type of double-layered façade, is prevented by the sectional limitations produced by the vents. However, door opening forces in some – particularly western – offices exceed the comfort level for 5% of operating time and borderline level for 2% of operating time, which leads to the conclusion that the double-layer façade is not able to prevent increased door opening forces on all places at all times. This led to the development of the control panels mounted in every office; the building 'communicates' with the occupants via the control panels by indicating whether windows can currently be opened or not. When wind speeds reach c. 8m/s at which point door opening forces can exceed acceptable levels, which happens on average around 300 hours per annum, the control panel indicates that windows must be closed. The windows must also be closed when the outside temperature falls to <2 °c, which happens on average around 100-250 hours per annum.

NATURAL VENTILATION THROUGHOUT THE BUILDING PROPELLING FORCES

Apart from possible differences in wind pressure on the various floors, the natural vertical ventilation throughout the building is predominantly propelled by the building's thermal conditions, i.e. the elevator and stairwell shafts 'chimney effect'. Therefore, there is excess atmospheric pressure in the upper floors and low atmospheric pressure in the lower floors. The area of equal atmospheric pressure is known as the neutral zone.

SMOKE EXTRACTOR AND PRESSURE REGULATOR FLAPS, ENGINE ROOMS

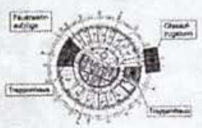
It was crucial to keep the smoke extractor flaps inside the elevator shafts and the pressure regulator flaps in the stairwell shafts closed to avoid air coming in via the entrance areas. Since lift force caused by low outside temperatures would have caused conventional pressure regulator flaps to open, we decided to install remote-controlled pressure regulator flaps in this building.

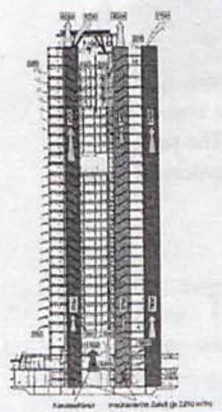
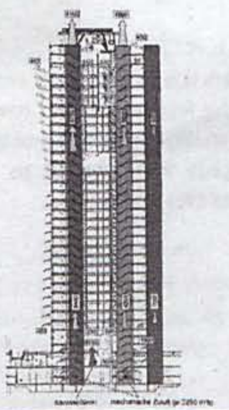
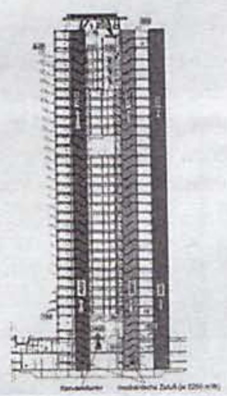


Driving forces in the vertical air streams throughout the building

LEFT
Thermics, upward air streams

RIGHT
Wind, up- and download air streams



			
smoke extractor in elevator	o	×	×
pressure stabilizer in stairwell	o	o	×
windows	×	×	×

NATURAL VENTILATION - PASSIVE

ELEVATOR DOORS, AIR LOCKS

Because the elevator doors are not completely airtight the architects planned air lock doors in front of the elevator doors in an attempt to reduce vertical ventilation throughout the building. The effect of the air lock doors can be seen using an example where office windows and doors are open, along with the resultant air-volume flow on the ground and level -1, which is connected to the ground floor via the lobby, as air lock doors have not been installed in this area.

LOBBY, TERRACE DOORS

The lobby area required special attention due to the external doors and the fact that the elevators link the lobby with a large number of floors. Within the context of fine-adjustments to air flow resistance within the building, measures to improve airtightness of

- revolving lobby doors
- stairwell air lock doors on level -1 to -3 and
- entrance air locks to the underground parking on levels -1 and -2 were taken.

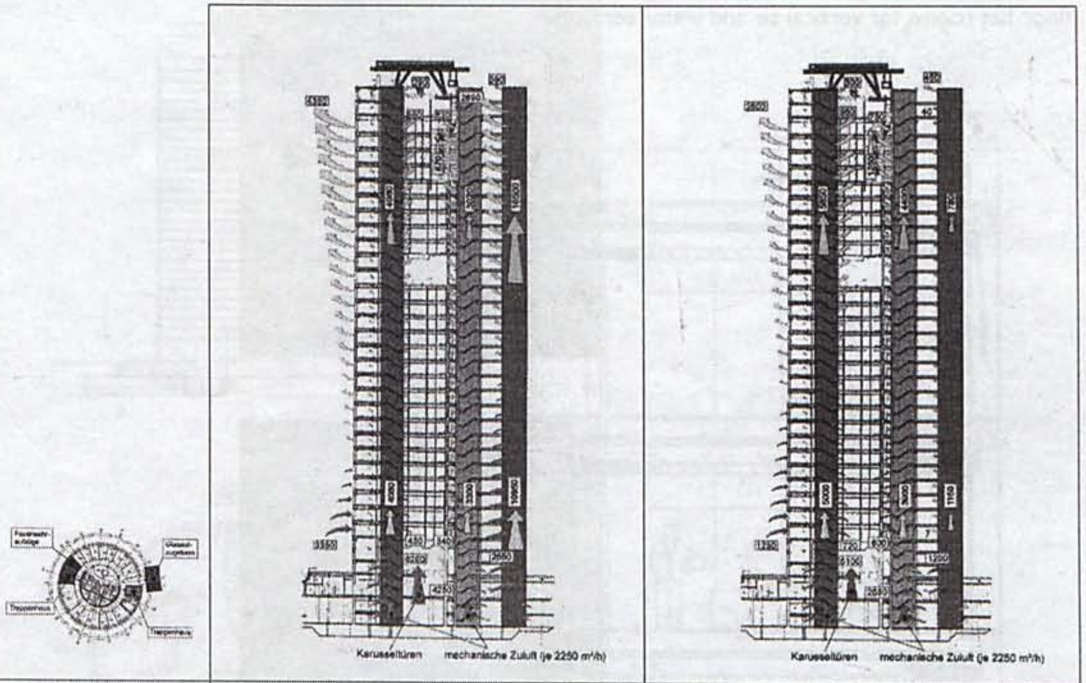
Furthermore, recommendations could be derived with regards to the airtightness of the hydraulic lift from level -3 to level 0 and preventing the opening of the terrace doors on levels -1 and 27 during the winter months.

OFFICE VENTILATION BY OPENING WINDOWS

The effects of natural vertical ventilation on office window-ventilation are moderate. The office door are very airtight, so that with office doors closed and windows open cross-ventilation remains below a 20-fold air change rate; with the doors open it increases to a 70-fold air change rate, which is still not sufficient to cause loose paper to fly about. The intensity of the ventilation can, of course, be easily reduced by closing individual office doors. Air speeds up to 0.3m/s are possible within this scenario, but this was considered acceptable if it only occurred for a short time.

DOOR OPENING FORCES, ELEVATOR SHAFT DOORS

Given the overall height of the RWE tower and the position of the neutral pressure zone, it was recommended that windows are only opened when outside temperatures are above +2°C, in order to avoid door opening forces higher than 100 N (10kg). Furthermore, the pressure differences around the elevator shaft doors were calculated and relevant guidelines were transmitted to the elevator manufacturer.



air locks in the glass elevator tower	o	x
windows	o	o

MECHANICAL VENTILATION - ACTIVE

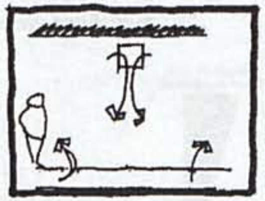
HVAC SYSTEM USED

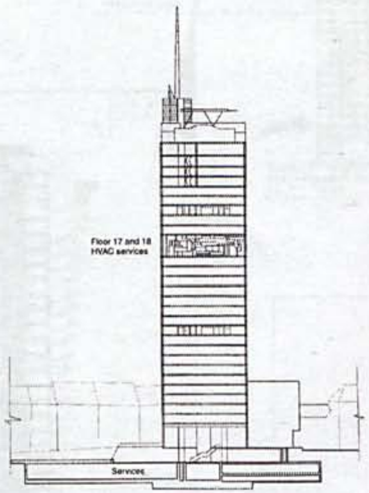
Displacement ventilation combined with chilled beam cooling

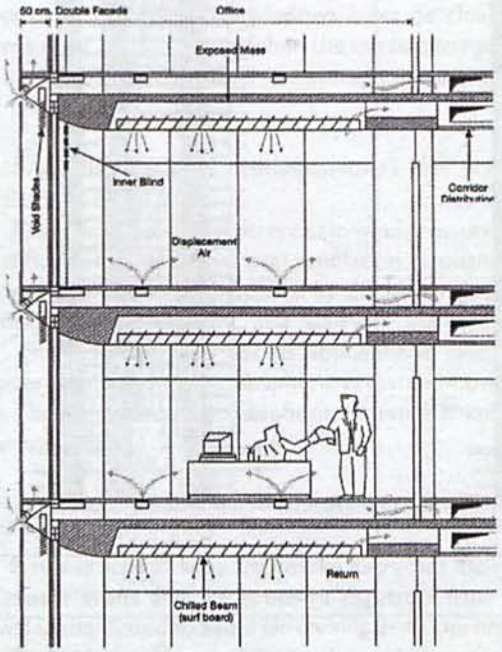
DESCRIPTION OF HVAC SYSTEM

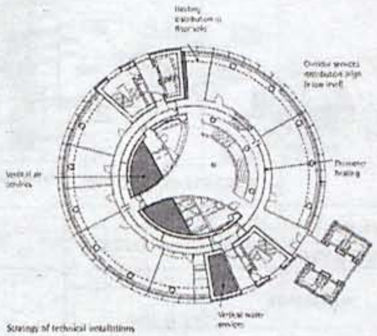
The active mechanical ventilation is provided by air supply and extract ducts running at a high level above the corridor ceiling with distribution to and from the ceiling space of each office. Each office has its chilled ceiling unit.

The two main air-handling units (17m³/s each), along with the three 700kW main chillers and heat-refection plant, are on Levels 17 and 18 about two-thirds of the way up the building, thus freeing up the roof for other functions. Each floor has rooms for vertical air and water services.

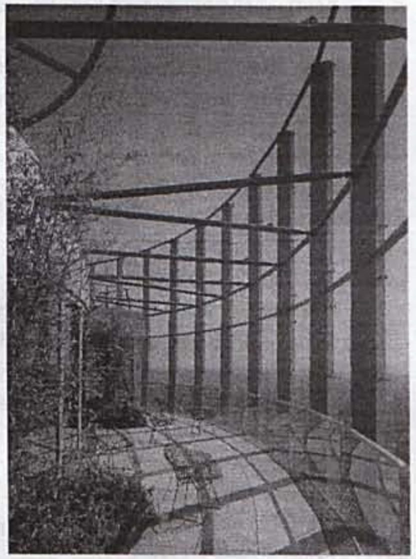


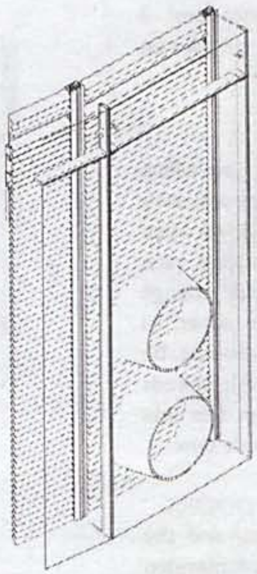


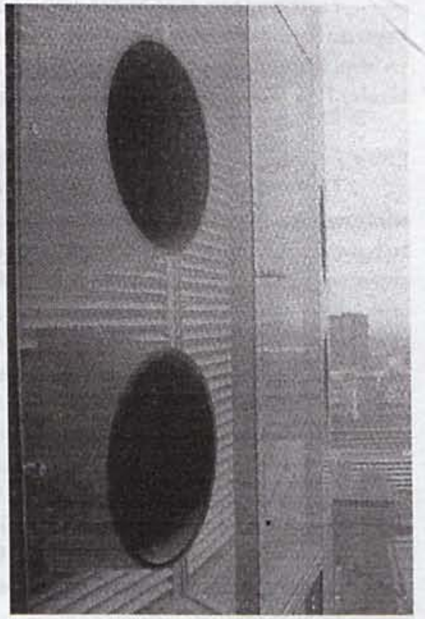




Extensive wind tunnel tests were undertaken to ensure that the various airflows from the air-handling units and the cooling towers would not interfere with one another or with the natural ventilation of the immediately adjacent floors. The exit nozzles are designed so that, in winter, the relatively humid exhaust air exits sufficiently fast that it mixes quickly with the drier outside air, thus avoiding condensation and the formation of icicles.



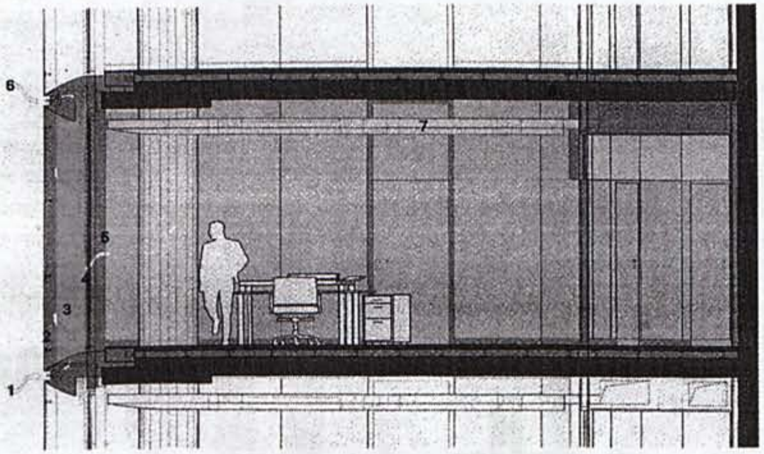




COOLING - PASSIVE

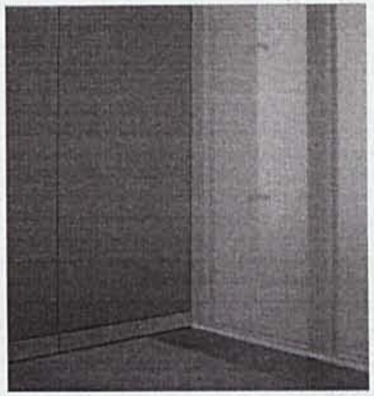
A THERMAL-FLUE CURTAIN WALL

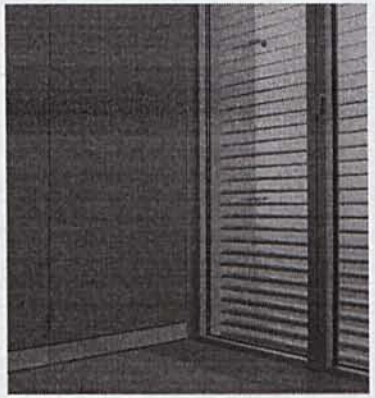
The buffer zone created between two planes of glazing offers an insulating layer in all seasons. In summer, it exhausts excess heat from internal loads and the sun.

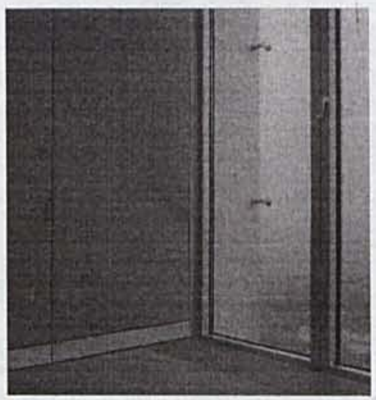


SUN PROTECTOR BLINDS

Daylight can diverted and dimmed thanks to the sun protector blinds inside the double layer facade and the interior anti-glare screen. The slatted blinds in the facade corridor have virtually the same effect as exterior sun protectors. The energy of the sun's rays beaming down is absorbed by the slats; this causes the slats to heat up, but the secondary heat transmitted by the slats remains within the infrared range and is largely deflected from the interior by the insulation of the glass. Adjusted appropriately, the blinds deflect more than 90% of solar energy from the building's interior. The exterior glass wall protects the blinds from wind, humidity and other climatic elements, so that even fitted to a high-rise building their safe and virtually maintenance-free operation is ensured over many years.







ISSUE 11
THERMAL COMFORT VENTILATION

MENARA UMNO

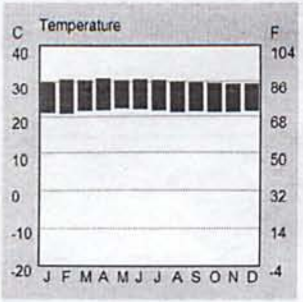
ARCHITECT
Hamzah & Yeang

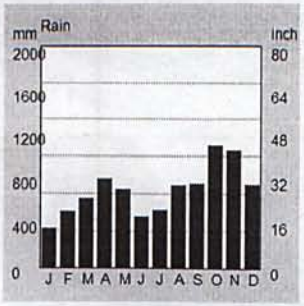
YEAR OF COMPLETION
1997

LOCATION
Georgetown, Penang, Malaysia

CLIMATE IN GEORGETOWN

Georgetown enjoys a warm equatorial climate and is similar to most destinations along the west coast of Peninsular Malaysia. Temperatures generally range between 29°C - 35°C during the day and 26°C - 29°C during the night. Throughout the year, the weather is mostly uniform.

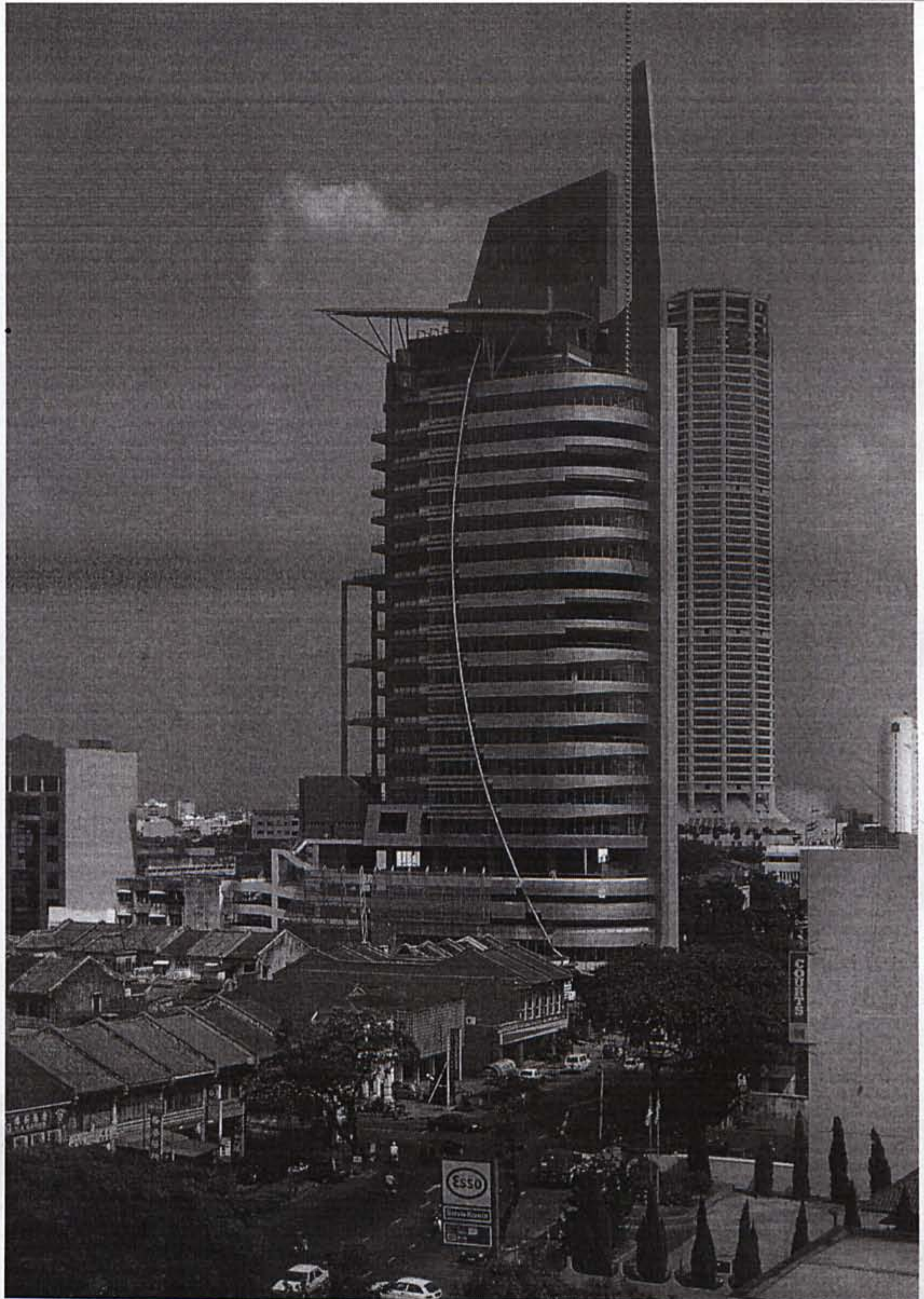




LEFT
Temperature chart
of Georgetown

RIGHT
Rainfall chart
of Georgetown

LEFT
Location
of Georgetown



BUILDING FORM

SHAPE OF THE BUILDING

A sculpted mass to encourage natural ventilation

NUMBER OF STOREY

21

ANY TAPERING TOWARDS THE TOP

None

HEIGHT OF THE BUILDING

Roof top 87m

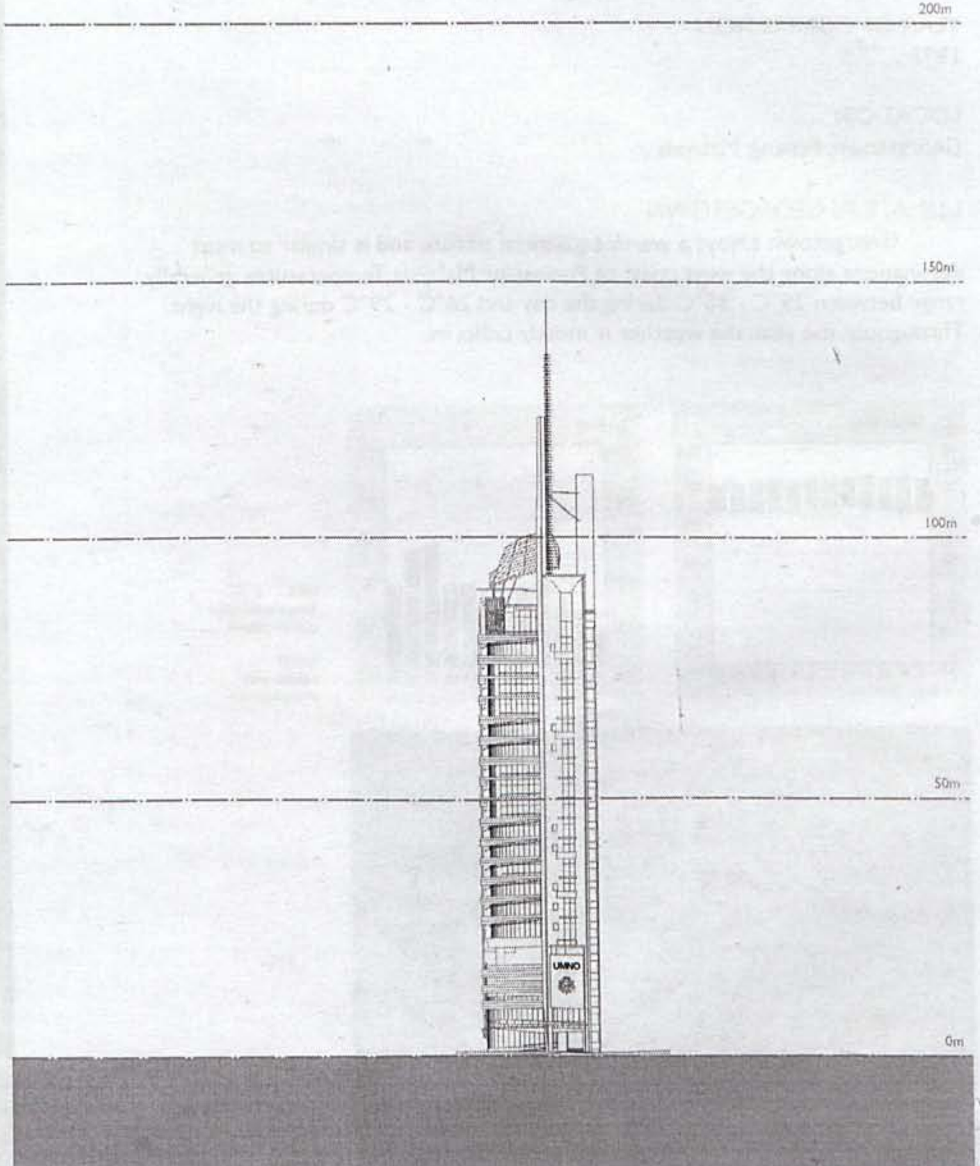
WIDTH OF THE BUILDING

Tower 21m

WIDTH TO HEIGHT RATIO

1 : 4.14

LEFT
Aerial photograph of the Menara UMNO

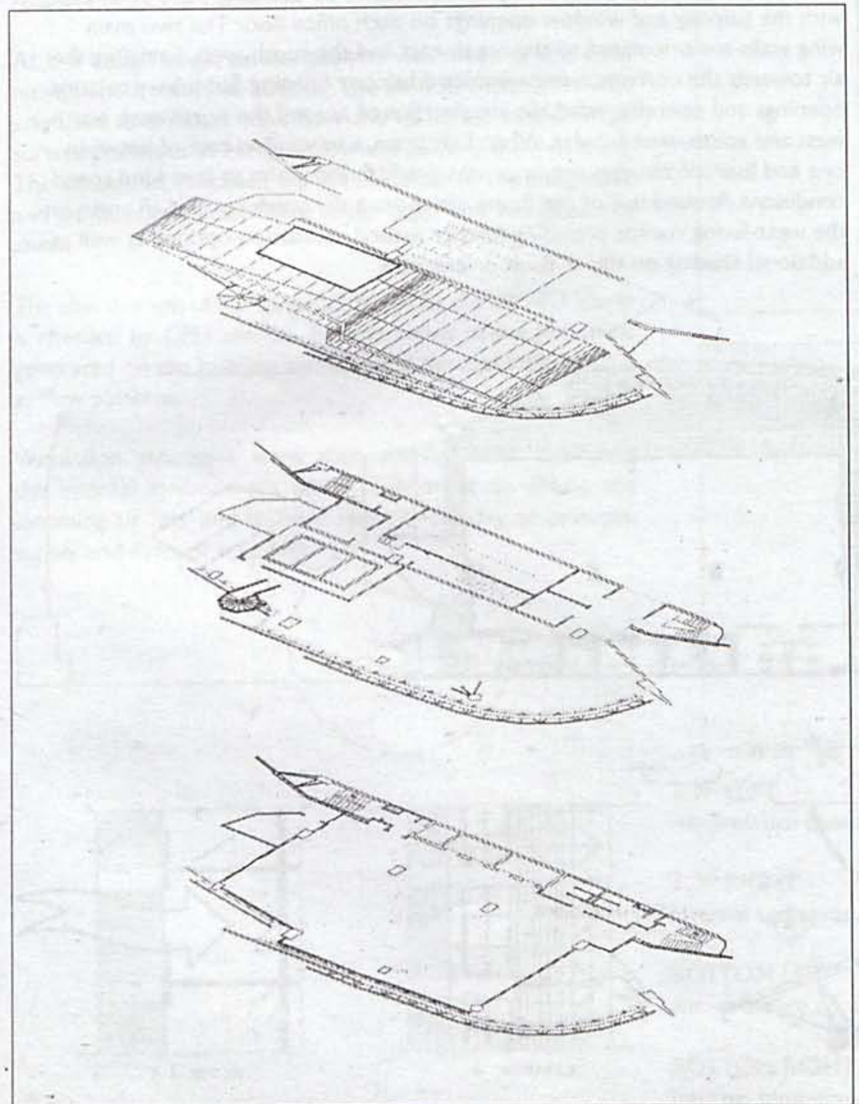


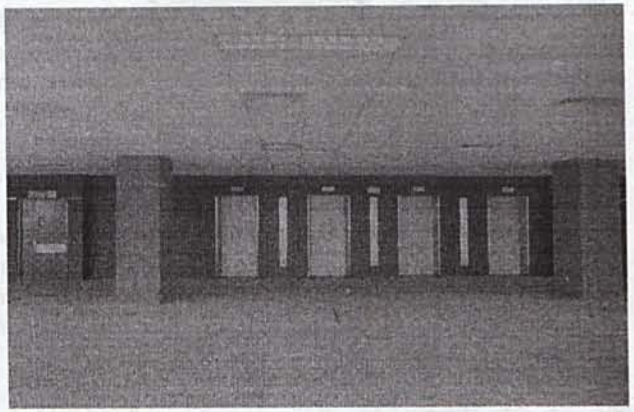
BUILDING SECTION 1 : 1000

BUILDING INTERIOR

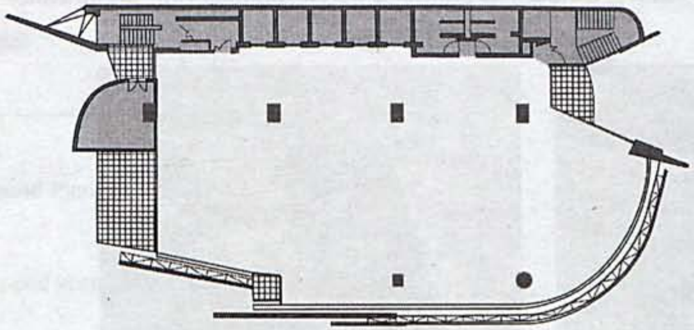
LOCATION OF SERVICE CORE

Lifts, toilets, stairwells and the AHU plant rooms are amalgamated into a solid sunshield which is located on the south-east and north-east side. It buffers the accommodation (the office space) behind from excessive heat and glare.





FLOOR PLAN SHOWING SERVICE CORES AND OTHER STRUCTURE ELEMENTS



TYPICAL FLOOR PLAN 1 : 350

APPROX. EFFICIENCY : 80%

NATURAL VENTILATION - PASSIVE

THERMAL COMFORT VENTILATION

The near equatorial latitude and warm, humid climate of this island location represent a real challenge to designers who wish to employ natural ventilation. To approach thermal comfort conditions, significant amounts of air movement are essential to achieve sufficient heat transfer from the skin of the occupants to compensate for the reduced opportunities for convection and radiation and all this must be balanced against the risk of papers or other lightweight items being blown around the space. Hence, Malaysian high-rise office blocks usually have sealed facades and full air-conditioning.

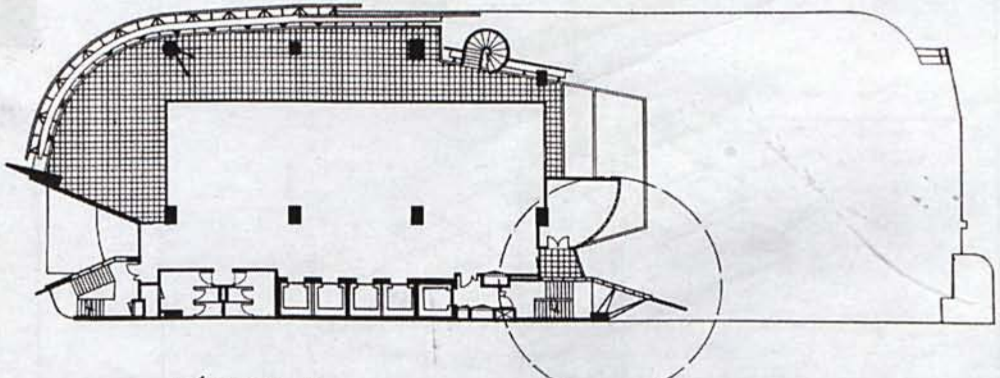
PREVAILING WIND DIRECTIONS

Assisted by the knowledge that the main wind directions were from the north/north-east and from the south-west, he designed a building that offered the potential for natural ventilation to be used as a significant provider of thermal comfort, while still making provision for tenants to install their own air conditioning systems.

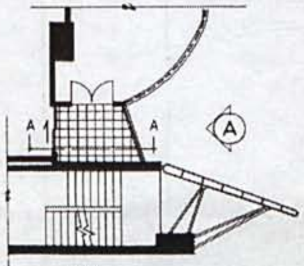
WING WALL

The principle of the wing-wall or wind-wing-wall is used here. Vertical walls the full height of the building protrude from the north-east and south-west eleavations. The prevailing winds are channelled into the building from the windward side and pressure zones are created on the leeward side. The use of 'wing-walls' is combined with variable transitional zones as ventilators. The principle of wind-walls is not new but in the past their use has been confined to low-rise buildings. As far as is known this is the first application of the technique in a high-rise building, although its principles were indicated by the performance characteristics of the MBf Tower in Penang, completed just over four years earlier.

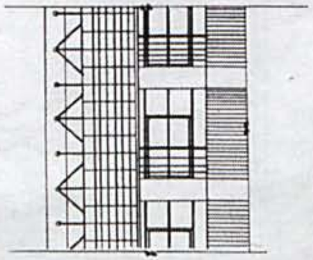
Passive environmental control is provided mainly by the wing walls in concert with the balcony and window openings on each office floor. The two main wing walls are orientated to the north-east and the south-west, funneling the air towards the corresponding windward balcony opening. Subsidiary balcony openings and operable windows are distributed around the north-east, north-west and south-west facades. When fully open, a ventilation rate of between one and four air changes per hour was predicted for calm to low wind speed conditions. Around half of the floors also have a sky court cut out an angle on the west-facing corner, providing further natural ventilation options as well as additional shading on this difficult orientation.



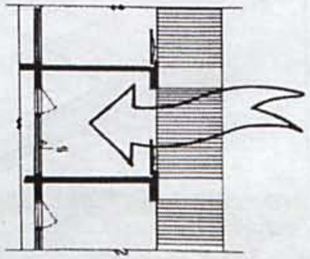
LEVEL 21



PLAN



ELEVATION A



SECTION A-A

NATURAL VENTILATION - PASSIVE

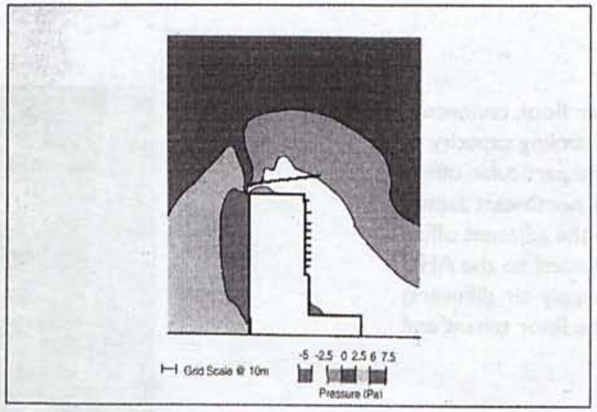
CFD ANALYSIS

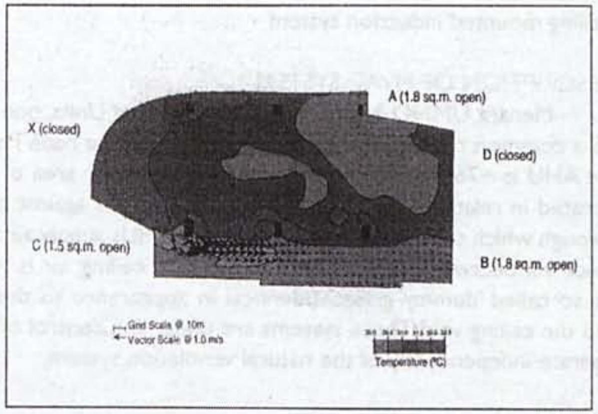
In the case of passive systems, a strategy for the upwind opening required to achieve a particular ventilation rate, under a range of outside winds has been formulated as a result of the CFD studies.

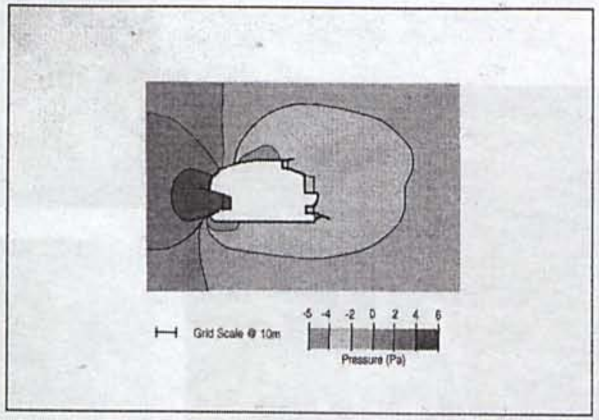
At the design stage, careful analysis was made of the wind movement around the building. The air-flow model DFS-AIR was used to simulate wind-flow and to obtain values of the surface pressures at each window and balcony door opening. The simulation indicated the effectiveness of the wing-walls and balconies in establishing clear high- and low-pressure areas.

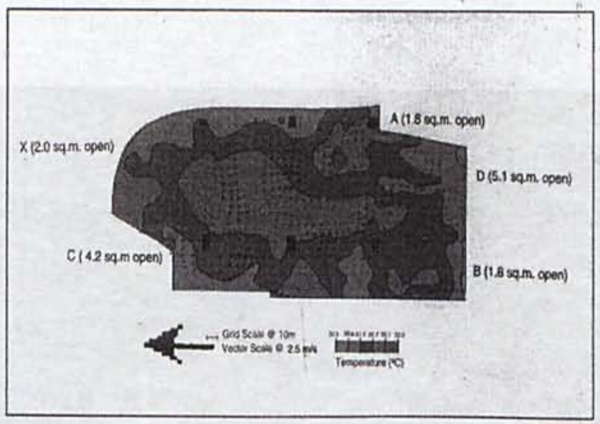
The effectiveness of the wing wall design for the UMNO Tower is checked by CFD analysis, both in terms of the pressures generated on the building surfaces and the resulting internal airflow patterns.

Ventilation strategies were then evolved after simulating the internal environment patterns in order to diffuse the incoming air 'jets' and to avoid short-circulating air between supply and exhaust openings.









TOP LEFT
Air-pressure contours show wind-flow around Menara UMNO (vertical section)

TOP RIGHT
Internal temperature distribution and air-speed vectors at 1.2 metres height

BOTTOM LEFT
Air -pressure contours show wind-flow around the tower at level 12

BOTTOM RIGHT
Internal temperature distribution and air-speed vectors at 1.2 metres height

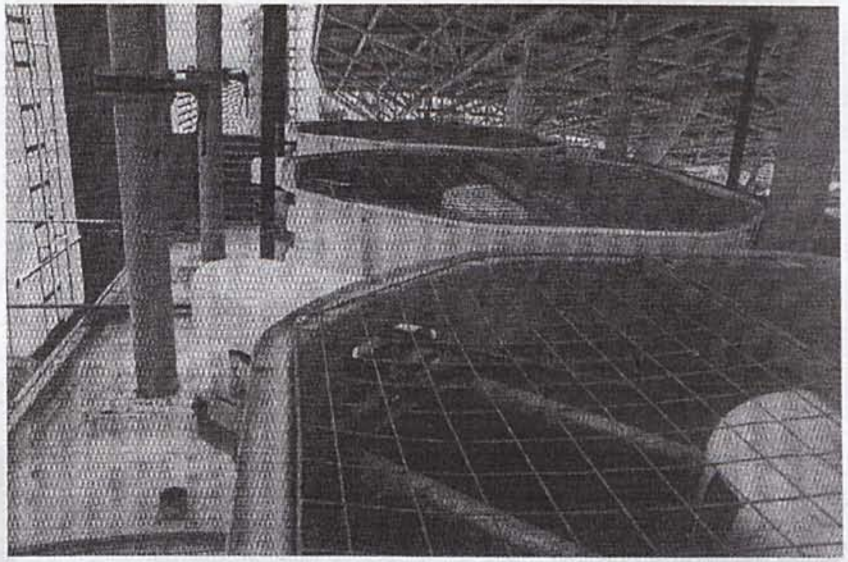
MECHANICAL VENTILATION - ACTIVE

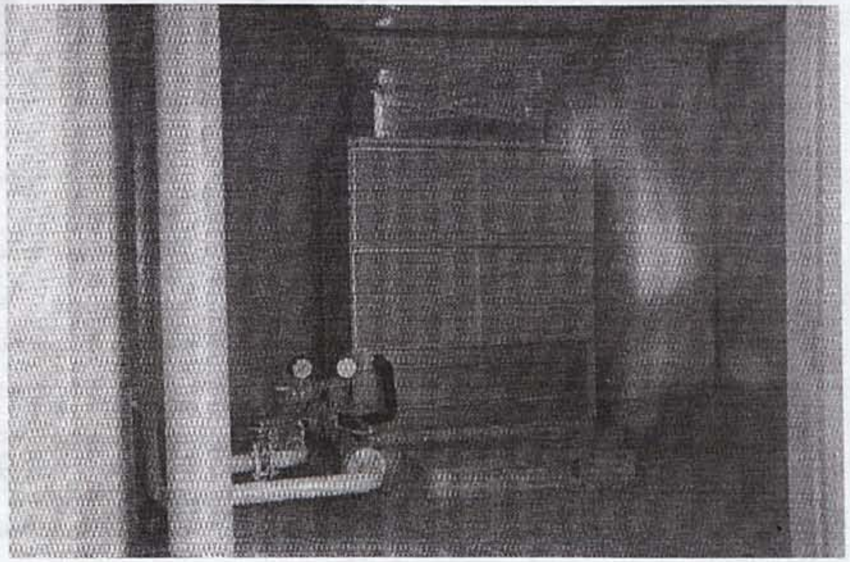
HVAC SYSTEM USED

Ceiling mounted induction system

DESCRIPTION OF HVAC SYSTEM

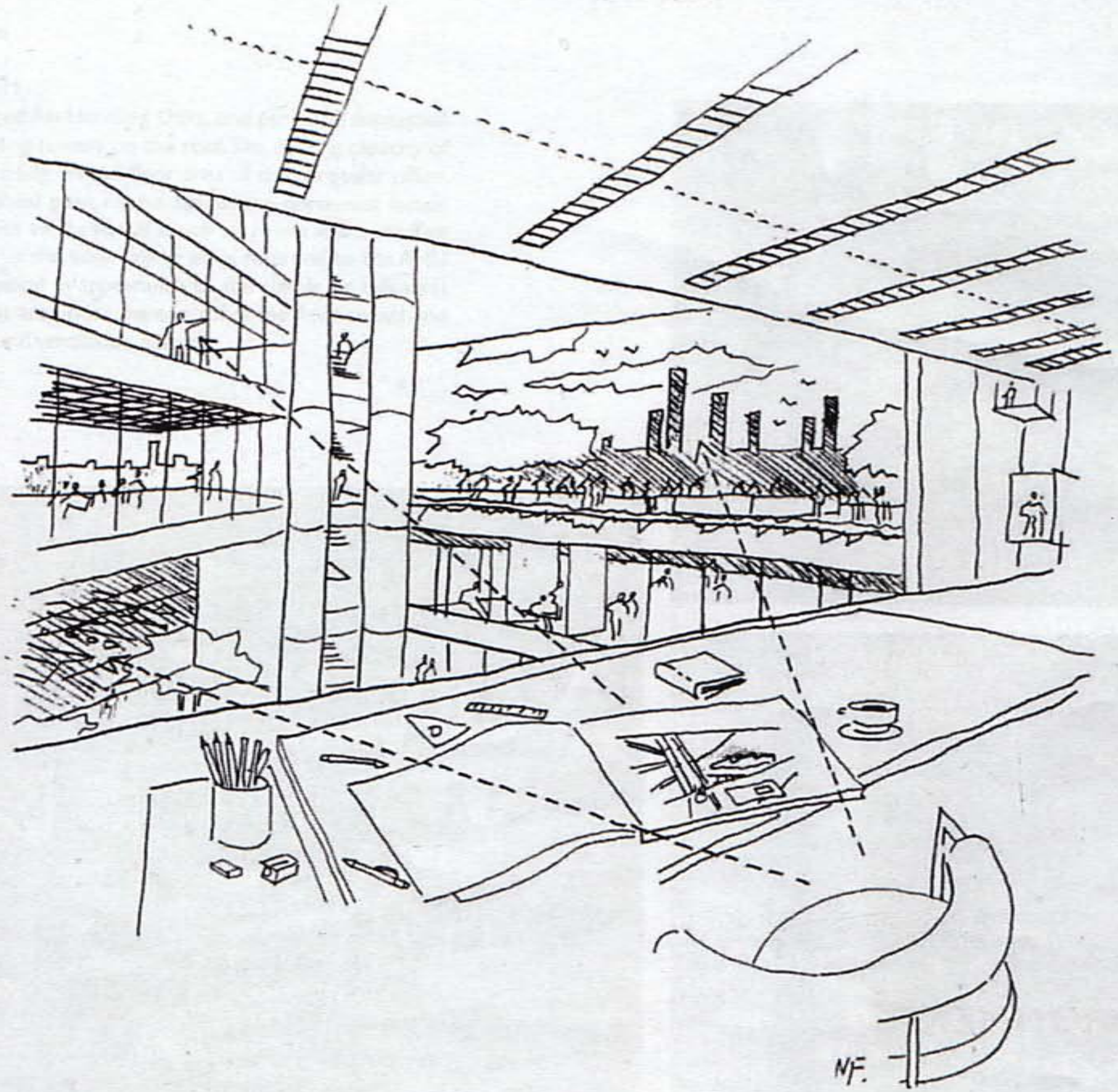
Menara UMNO has packaged Air Handling Units, one per floor, connected via a common riser to three cooling towers on the roof. The cooling capacity of the AHU is ~76 or 100kW depending on the floor area of the particular office. Located in relatively generously sized plant rooms against the north-east façade through which they draw their fresh air, the AHUs supply air to the adjacent office space via ductwork and diffusers in the false ceiling; air is returned to the AHU via so called 'dummy grilles' (identical in appearance to the supply air diffusers) and the ceiling void. These systems are under the control of the floor tenant and operate independently of the natural ventilation system.





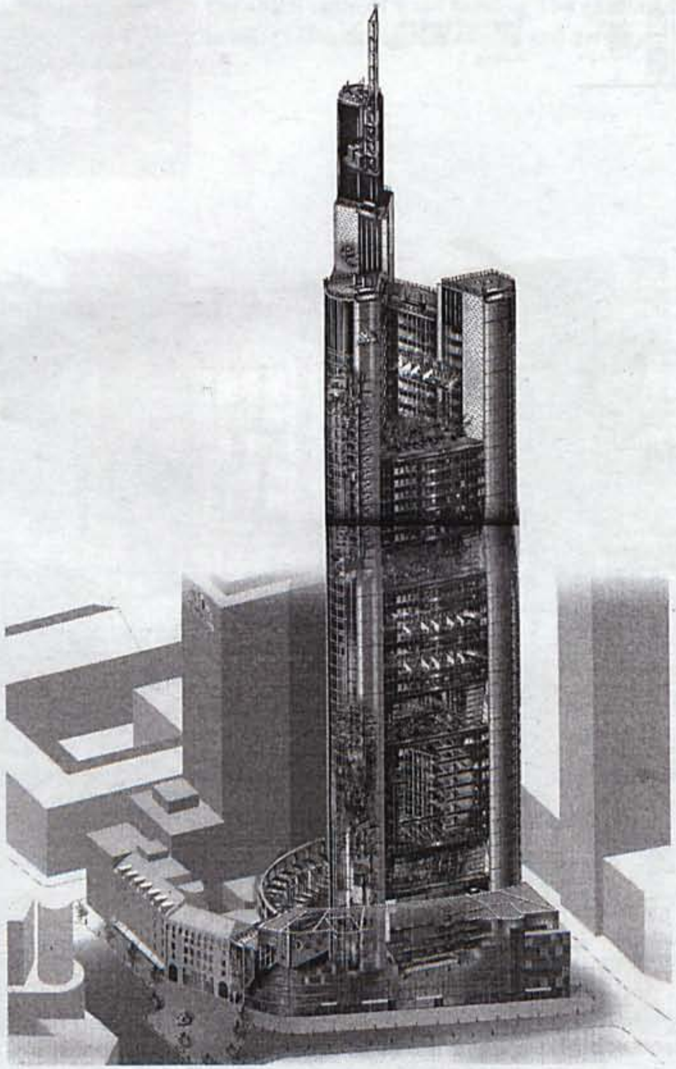
ISSUE III
WORKING ENVIRONMENT

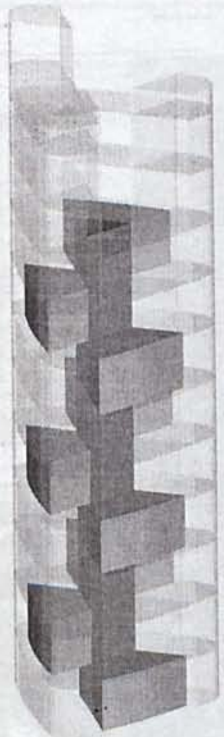
CONCEPT



Distribution

The four-storey-high winter gardens are evenly distributed over the height of the building. They are distributed in a spiral manner around the perimeter of the triangular plan as well as the central atrium.





The distribution of the winter gardens over the height of the tower

The spiral pattern of the winter gardens around the central atrium

ORIENTATION

Orientation

In order to make the air flow more manageable, the central atrium is divided into twelve-storey-high sections separated by glass decks. Each section formed in this way includes three winter gardens, one on each face of the building. This orientation of the winter gardens makes an almost perfect arrangement for efficient cross ventilation as there is always a windward garden to admit fresh air and a leeward garden to exhaust it.

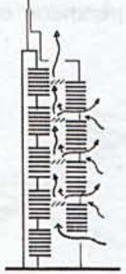
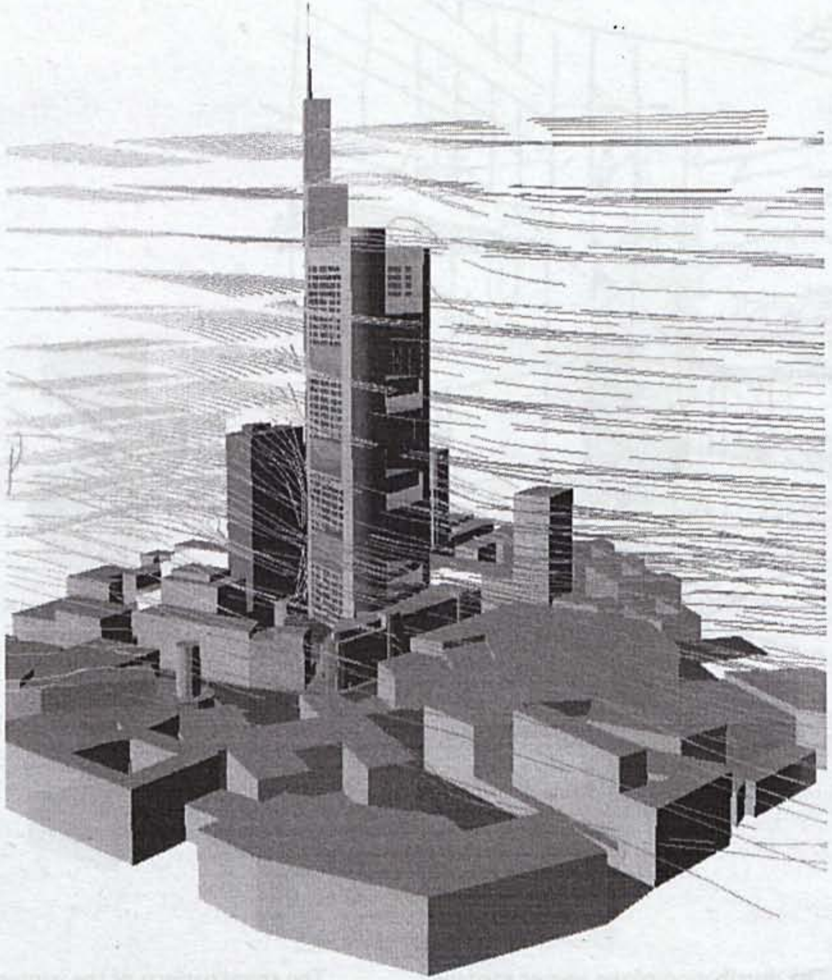
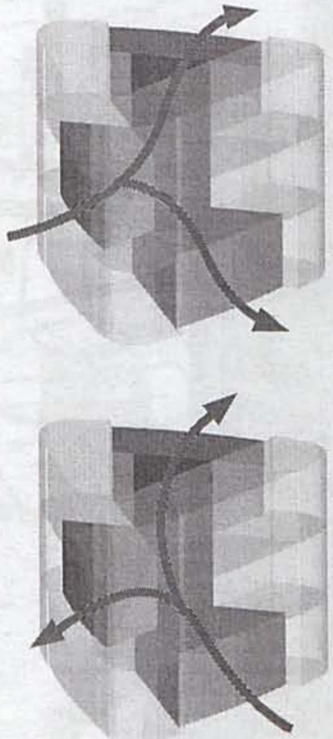
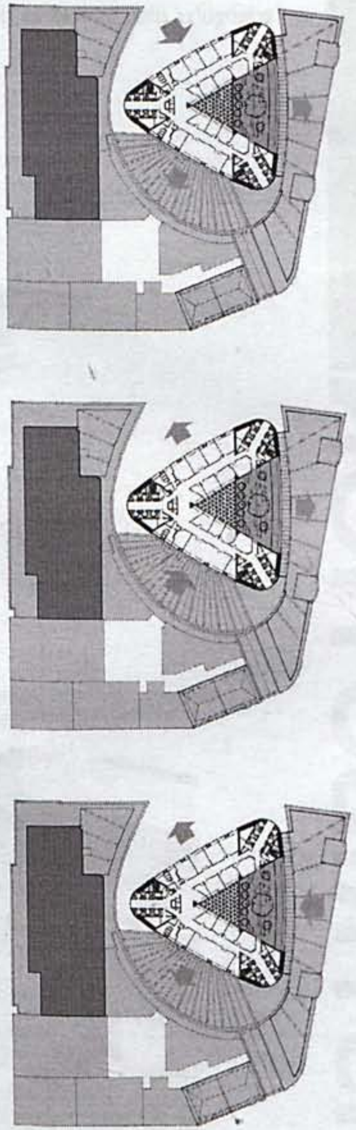


Diagram showing the natural ventilation method of the building



Detailed analysis of air flow patterns around and through the building was undertaken using computational fluid dynamics



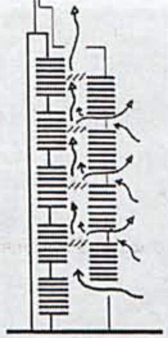


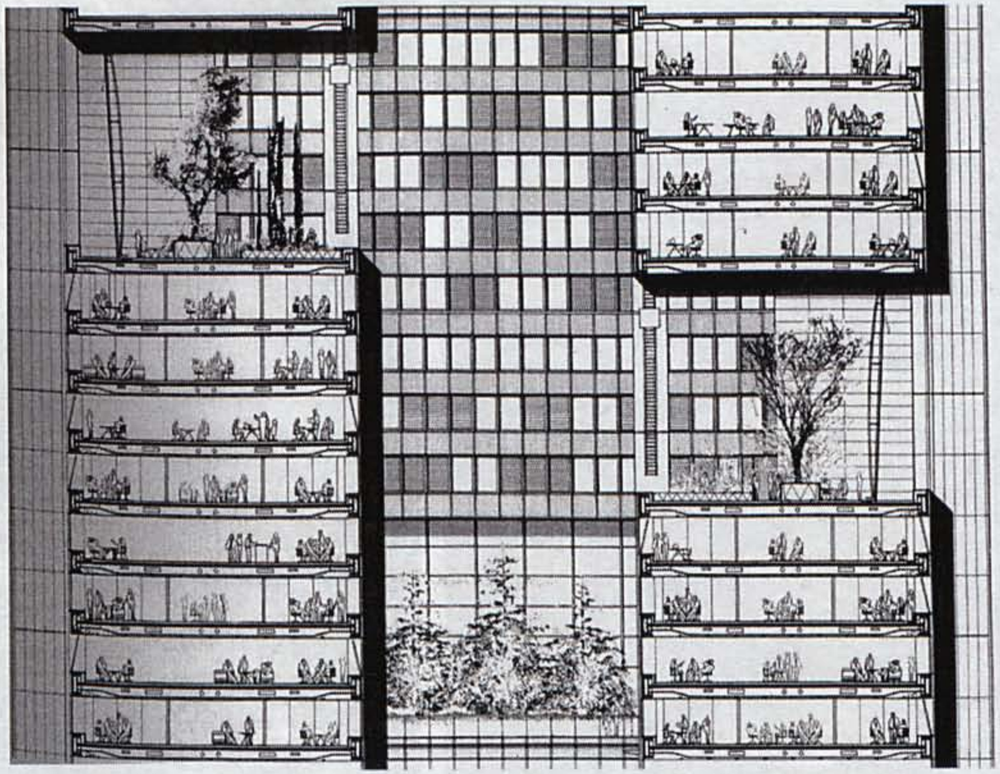
The orientation of the winter gardens allows efficient cross ventilation as there is always a windward garden to admit fresh air and a leeward garden to exhaust it

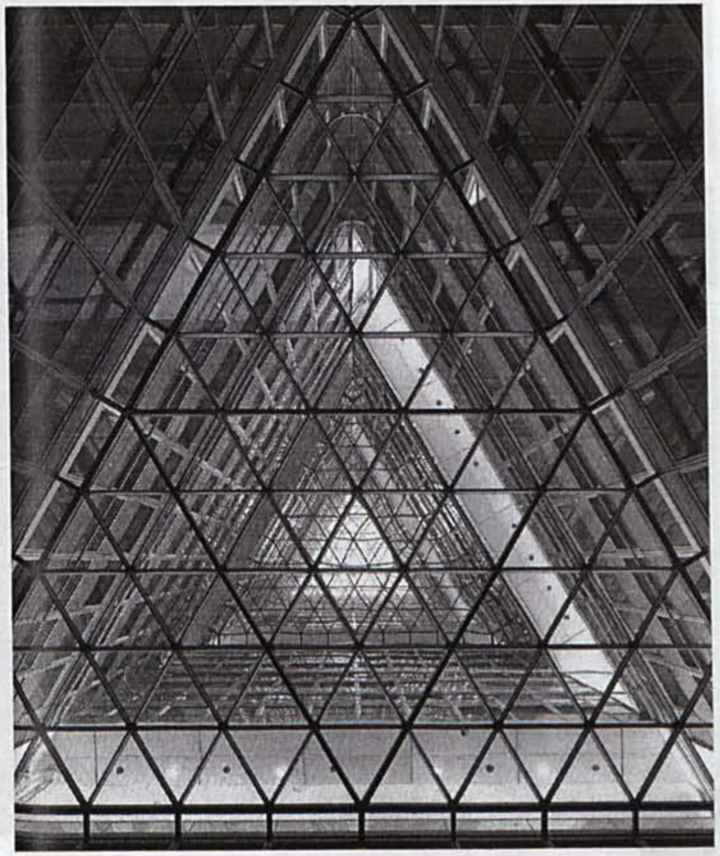
Interrelation

In the early stages of the atrium was envisaged as a giant 'chimney', using the stack effect to draw fresh air in through openings in the gardens' external glazing and exhaust it at the top. Instead, in order to make the flow of air more manageable, the atrium was divided into nine-storey-high sections separated by glass decks. Each section – or 'village' – formed in this way included three gardens, one on each face of the building.

The idea of breaking down the social scale of a tall building. The gardens help to create a greater sense of community by unifying the village-like clusters of offices and gardens. Externally, they articulate its mass, creating points of interest.





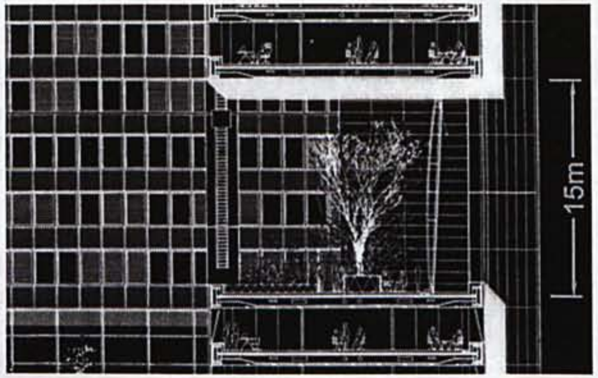


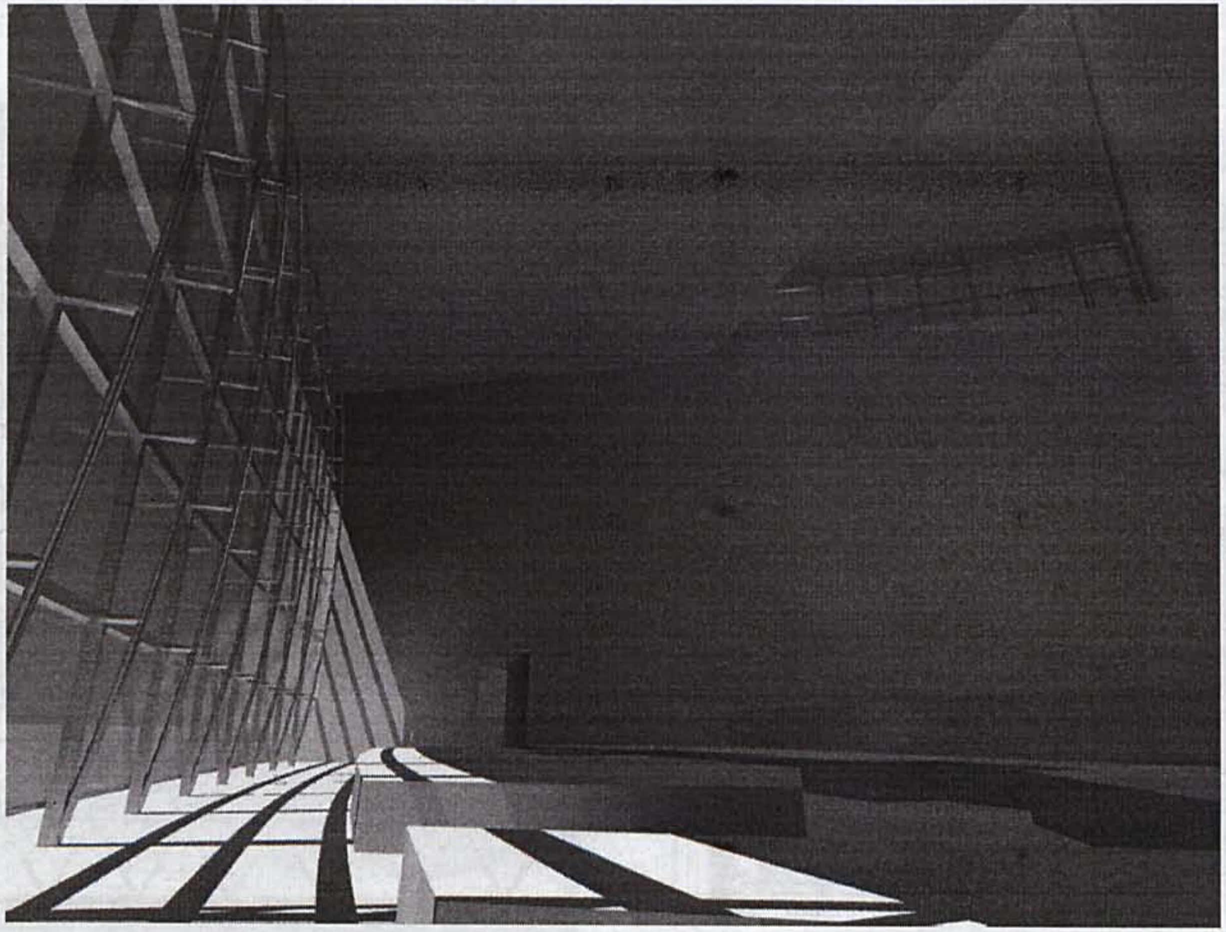
FORM

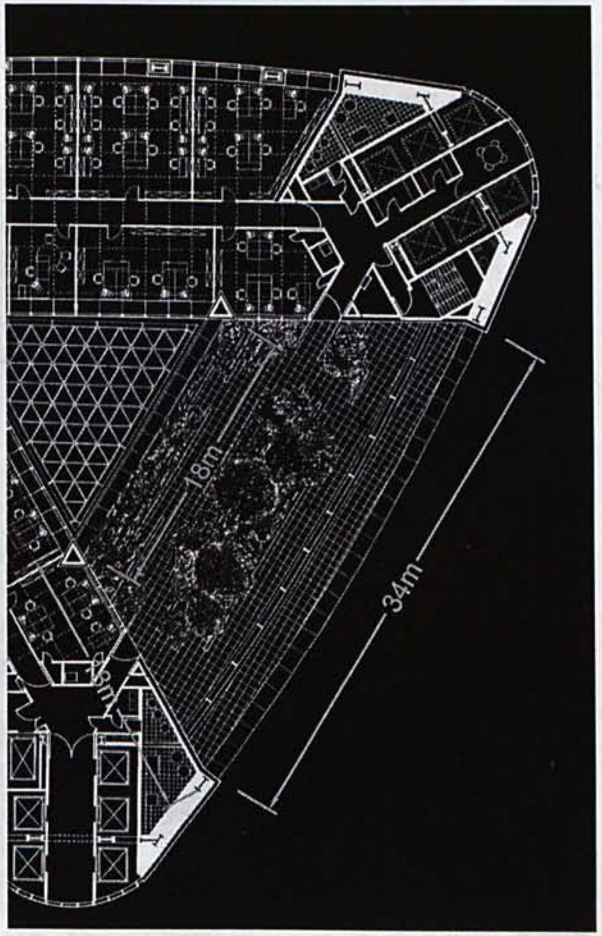
Form

The winter gardens give the building its human quality and they have a cladding system of their own. In every winter garden, a glazed curtain wall is set back from the surface of the monolith and slopes outwards. This break in the vertical plane is a clear sign of the importance of these communal spaces. But it has other functions too. It makes room for an external terrace at garden level and it reduces the pattern of reflections on the façade, revealing the interior greenery to general view.

A computer model is created to study the form of the space and its daylighting quality.



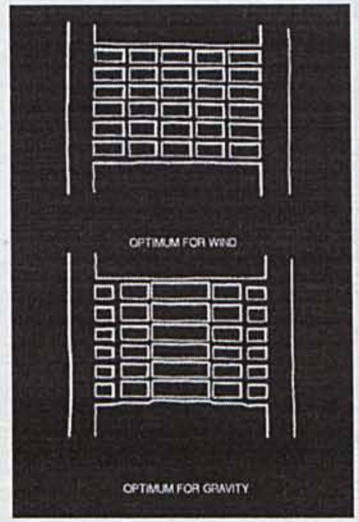


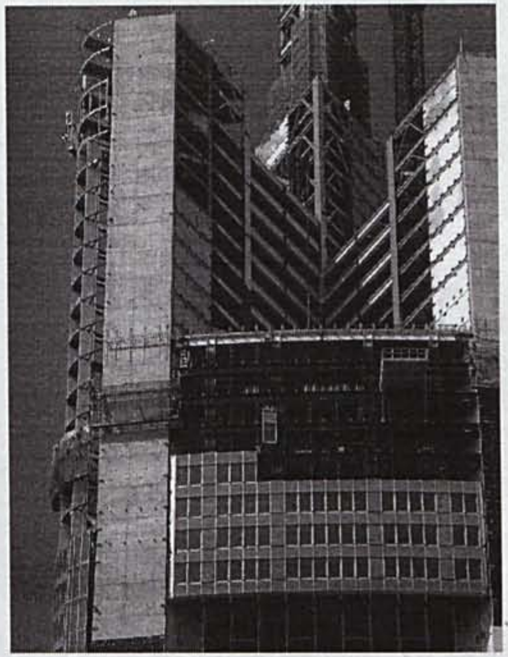


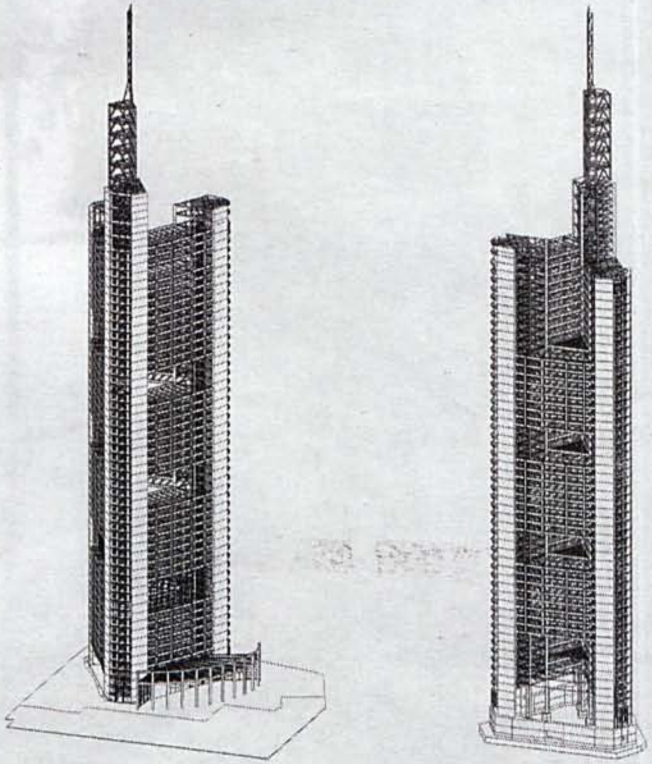
Structure

The 'perforated tube' structural option is inherently stable and resolves all structural conflicts at once. It allows most of the vertical loads to be concentrated at the three corners. The office floors bridge between these points, supported on eight-storey-deep Vierendeel trusses, which span the gardens.

The vierendeels perform two principal functions: they distribute the loads of the office floors uniformly through the structure, and they act with the corner columns to resist wind loading, absorbing lateral forces in rigid moment joints. This arrangement allows the gardens to be column-free; and because the floor structure at every fourth level is continuous around the building, these floors form stiffening diaphragms, providing stability over the full height of the tower. But this is more than just a structural solution. The 'donut' plan cleverly combines the structural advantages of a deep plan with the environmental benefits of a shallow one and allows the use of daylight and natural ventilation.







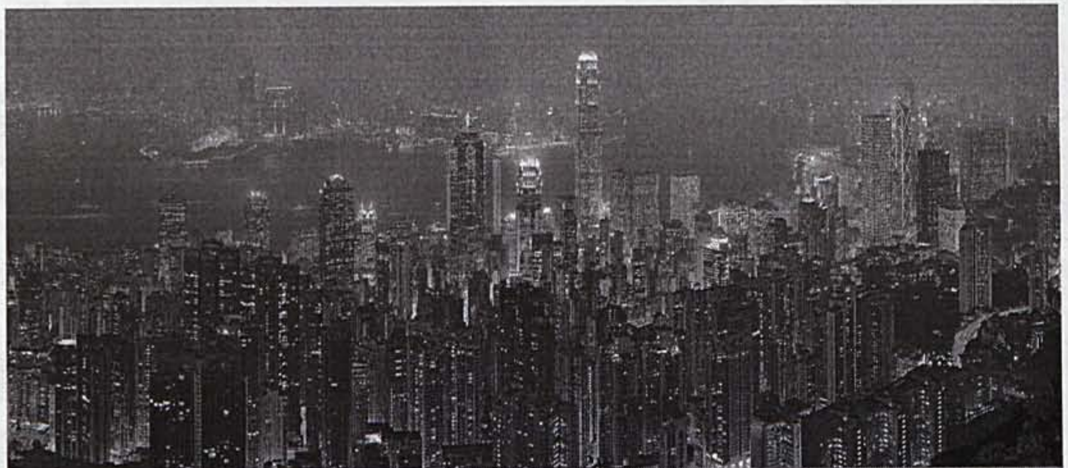

INTERIOR VIEW

FINAL DESIGN

THESIS STATEMENT

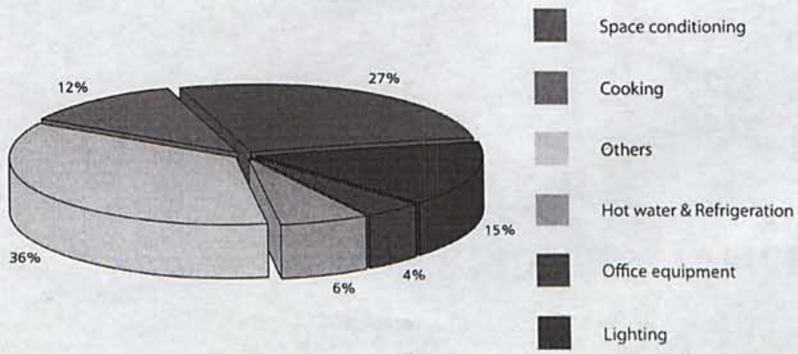
This thesis is to demonstrate a prototype for an ecological high-rise office building in Hong Kong and the objectives of this thesis are:

- **to achieve thermal comfort in office space by hybrid ventilation to reduce energy consumption required for comfort cooling; and**
- **to introduce nature into high-rise office working environment**



In Central and Sheung Wan, we could find a lot of 'sealed glass box' high-rise office buildings. These hermetically sealed high-rise office buildings require a significant amount of energy for comfort cooling, especially in summer because of the hot and humid climate at that time. To improve the situation, achieving thermal comfort by utilizing natural ventilation has to be made an important agenda in high-rise office building design.

Carbon dioxide is generally considered to be the main cause of global warming. In 2006, office sector consumed 15,085 terajoule of energy, which emitted 2,480,397 tonnes of carbon dioxide to our atmosphere, and among all kinds of energy end-uses in commercial sector, space conditioning remained the single largest consuming item in the last ten years. Therefore, utilizing natural ventilation can reduce our dependence on fossil fuel energy for space cooling and thus help cutting down carbon dioxide emissions.

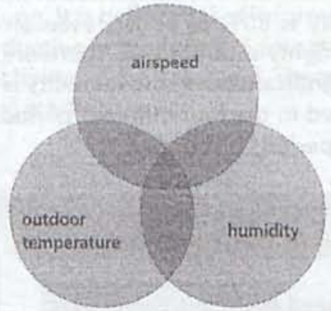


Commercial Energy End-uses in 2006, Hong Kong Energy-use data 2008 by EMSD

RESEARCH

indoor thermal comfort

There are three factors controlling indoor thermal comfort. They are outdoor temperature, airspeed and humidity respectively. The relationship between outdoor temperature (indoor air temperature), airspeed and comfort level can be studied in the chart below, which shows that higher airspeed can increase the upper limit of the comfort temperature range. The reason is that, besides increasing convective heat loss as long as the temperature of the moving air is less than the temperature of the skin, airspeed accelerates evaporation and thus provides a physiological cooling.



Comfort Temperature of Naturally Ventilated Buildings in Hong Kong

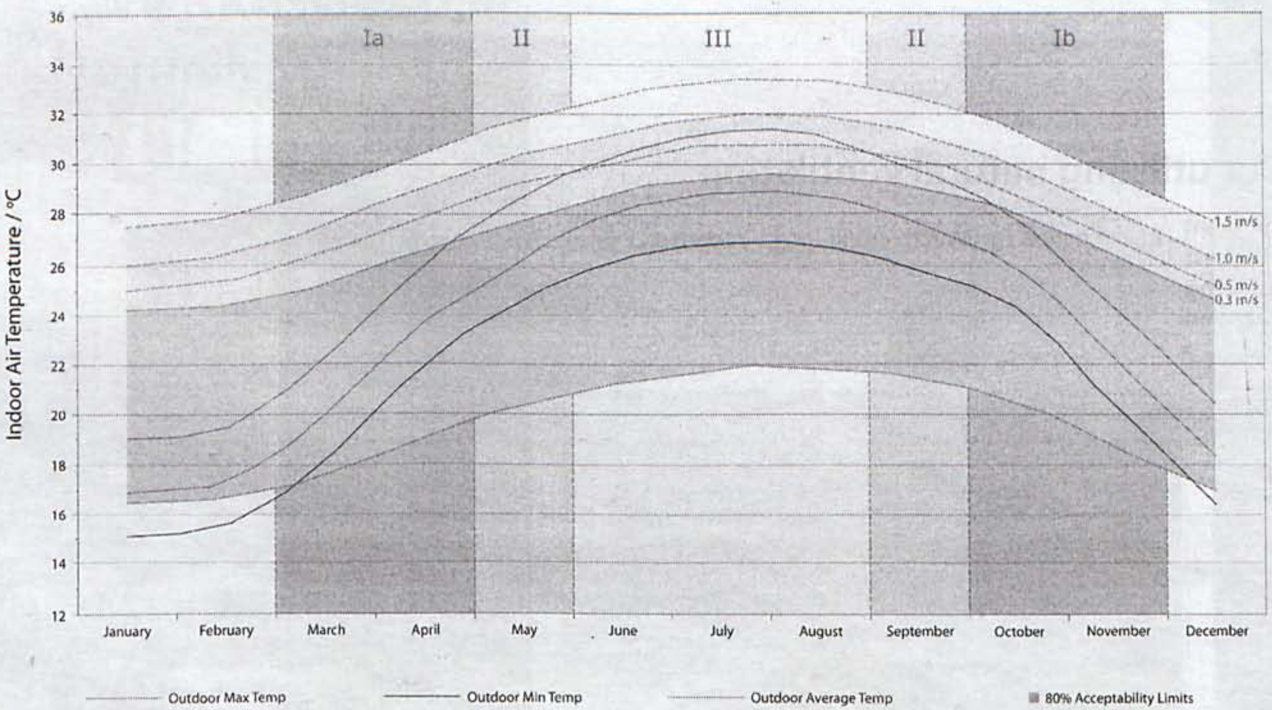


Chart Above: Reproduced from Architectural Science Review, Vol 49.2, Cheng, V. and Ng, E., Comfort temperature chart for naturally ventilated buildings in Hong Kong, pp. 179-182, Copyright 2006.

According to the chart above, the airspeed required in the four different periods to achieve indoor thermal comfort can be summarized in the table on the right.

However, when humidity is 80% or above, even air movement can't help add water vapour to the already highly-saturated air. Therefore, the effect of physiological cooling by evaporation is insignificant when the humidity is high. In order to determine the ventilation strategy applied in the four different periods, the number of days with humidity below 80% in these periods is counted.

	Controlling the airspeed to achieve indoor thermal comfort
Ia / Ib	Maintain the airspeed at around 0.0 - 0.3 m/s
II	Increase the airspeed to 0.5 m/s
III	Increase the airspeed to 1.0 m/s

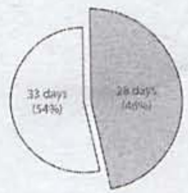
time of year allowable for utilizing natural ventilation

After analyzing the humidity level in the four different periods, we can notice that period Ib has the highest number of days with acceptable humidity level for utilizing natural ventilation. Different ventilation strategy is applied in different period as shown in the table below.

	Ventilation strategy applied
Ia	Hybrid ventilation (lower chance of utilizing natural ventilation)
Ib	Hybrid ventilation (higher chance of utilizing natural ventilation)
II	Mechanical ventilation
III	Mechanical ventilation

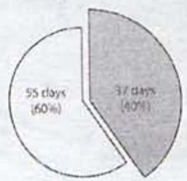
period Ia (March - April)

period II (May / September)



period Ib (October - November)

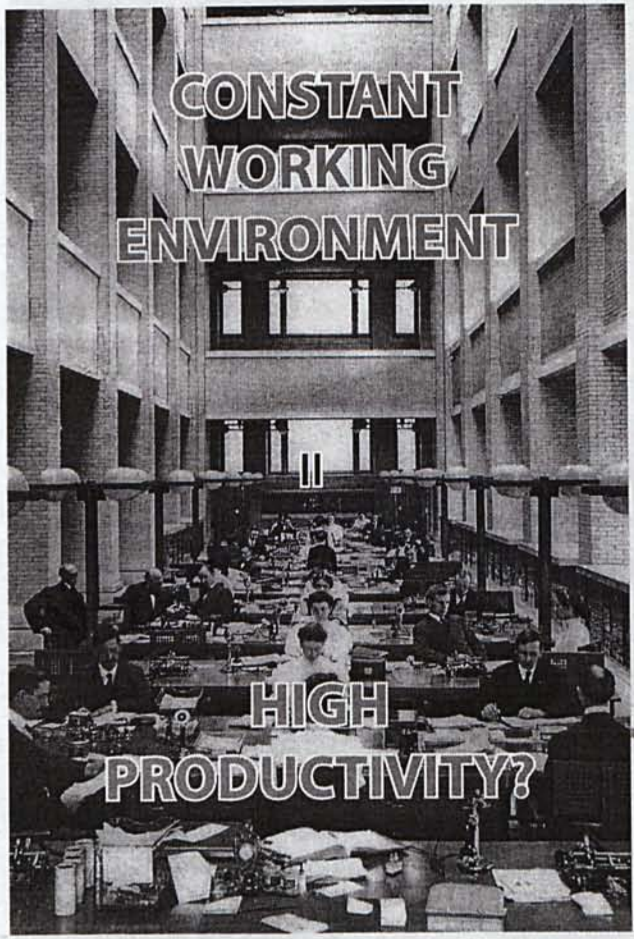
period III (June - August)



Number of days in the period of time with humidity below 80% in 2008

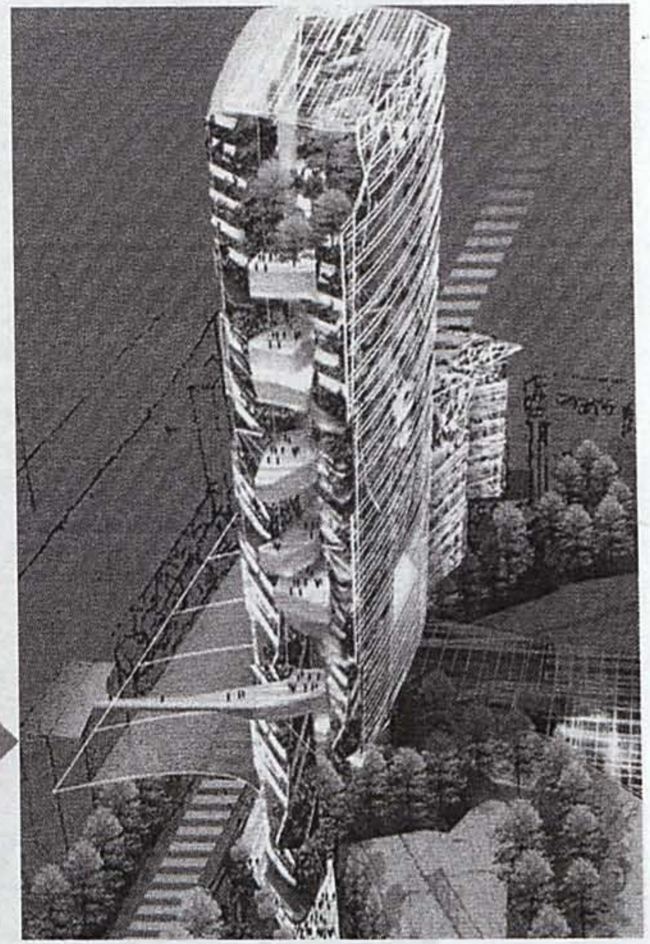
introducing nature into office working environment

Office working environment has changed little since the first appearance of office buildings in Hong Kong. It is believed that information technology will entirely change office work nature and this will require staff to be more self-motivated, more creative and more productive in the future. Some studies have shown that if staff is allowed to have visual connections with nature or to relax themselves in nature during break, their productivity will be improved. Therefore, introducing nature into high-rise office buildings can help corporations become more productive and thus competitive in the global market.



Larkin Building (1904-50)

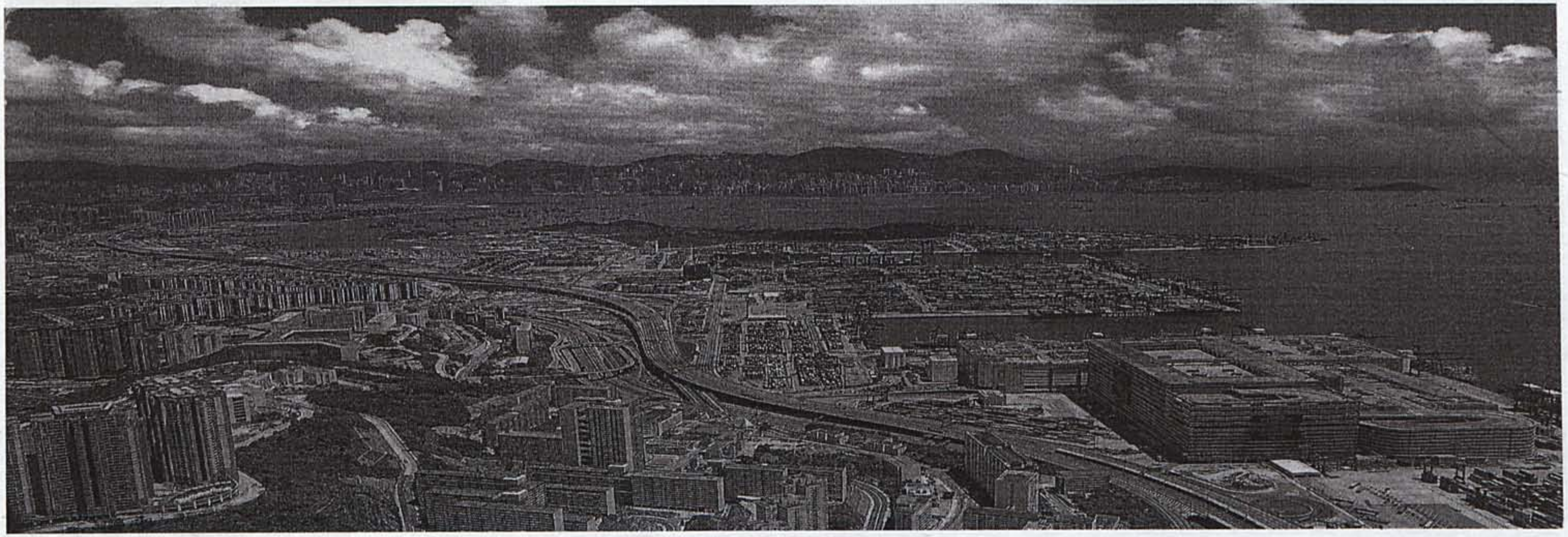

Willis Faber and Dumas Headquarters (1975-)


Elephant and Castle Eco Tower (2001)

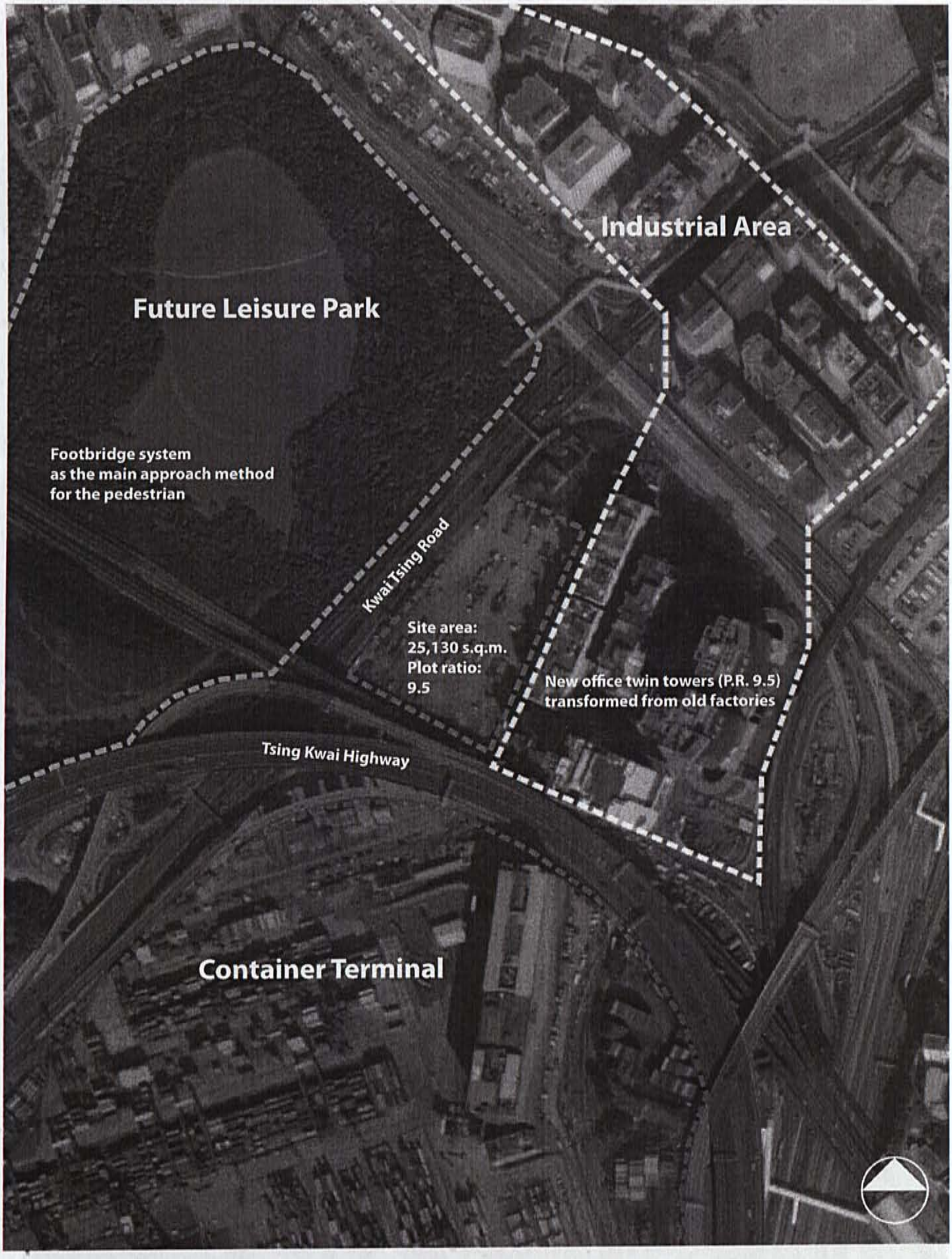
SITE ANALYSIS

office view

View is a very important consideration when selecting a site for an office building. The site selected for the design is located in the southern part of Kwai Chung and is very close to the Kwai Chung Container Terminal and the future leisure park proposed by the government. Therefore, most office space can have a view of at least one of the two. Offices at higher zones can even have a view of the Rambler Channel.



View of Kwai Chung Container Terminal

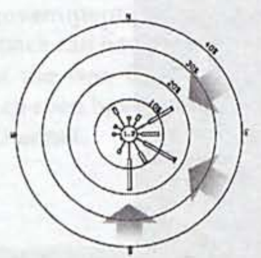


Industrial Area
Future Leisure Park
Footbridge system
as the main approach method
for the pedestrian
Kwai Tsing Road
Site area:
25,130 s.q.m.
Plot ratio:
9.5
New office twin towers (P.R. 9.5)
transformed from old factories
Tsing Kwai Highway
Container Terminal

connection with nature

Besides visual connection with the future leisure park, a physical connection in the form of footbridge will be proposed to encourage people to make use of the park to relax or even to work, which extends the office space to the surroundings and suggests a new working style.

prevailing wind direction



Summer prevailing wind direction (June - August)

Winter prevailing wind direction (December - February)

The prevailing wind direction in summer is from the south while those in winter are mainly from the east.

Annual Wind Rose for Ching Pak House Weather Station in 2006

noise

The high traffic load of Tsing Kwai Highway and Kwai Tsing Road needs design consideration regarding the problem of noise.

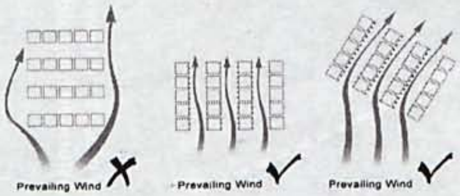
*Air pollution is beyond the scope of this thesis.

SITE STRATEGY

orientaion of tower

The 'northeast-southwest' orientation of the tower is:

- to maximize the view of office;
- not to block the southern summer prevailing wind and to utilize it for generating electricity for space conditioning;



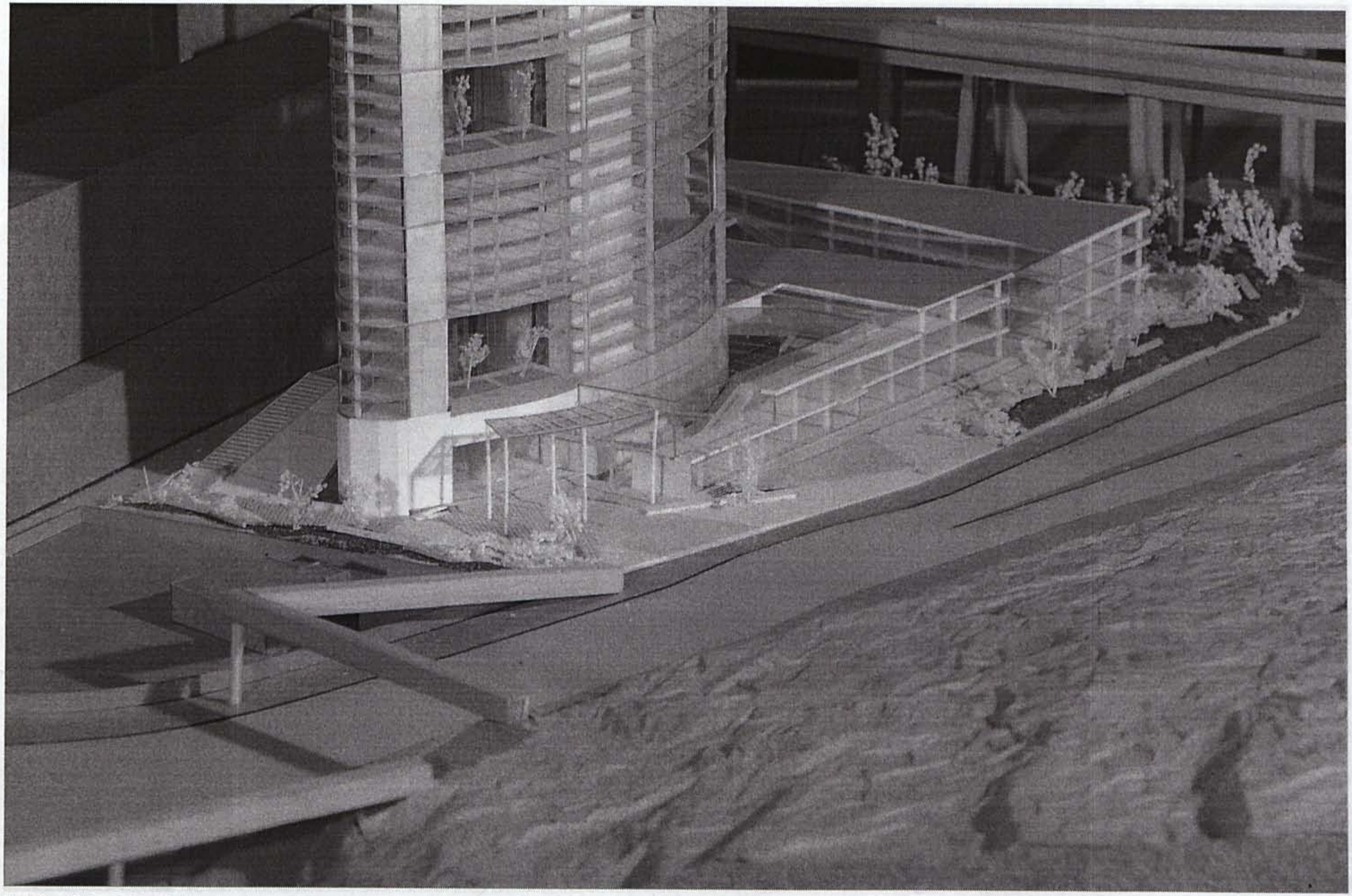
Chapter 11, Urban Design Guidelines, Planning Department

- to utilize natural ventilation in period Ia and Ib;
- to maximize the solar penetration;

set-back of podium

The podium is set-back on the sides facing Tsing Kwai Highway and Kwai Tsing Road to create a buffer zone between the building and the busy traffic.

Overall View with Site Context



View from Future Leisure Park

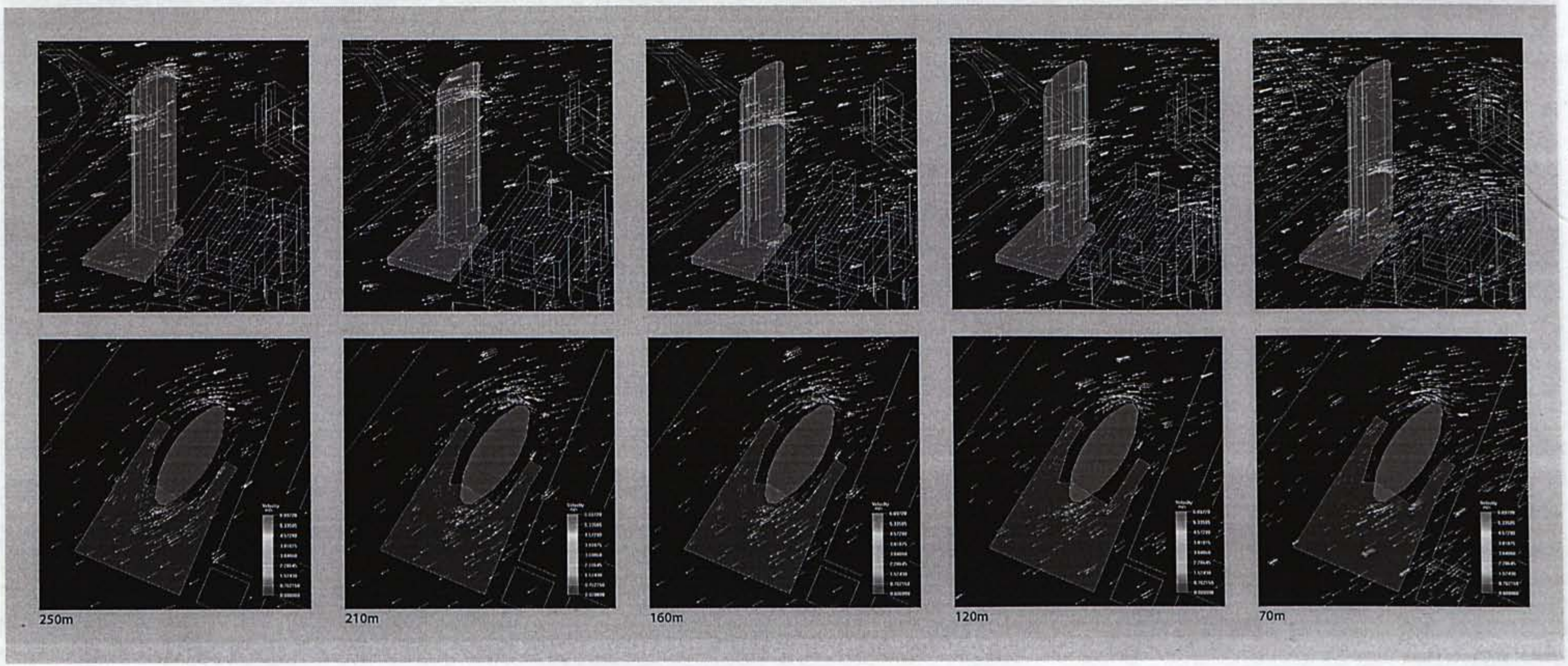
View of Entrance Plaza

CFD SIMULATION

Computer Fluid Dynamic (CFD) analysis is used during the design stage to establish the ventilation strategy for comfort cooling. The result of the CFD analysis can provide valuable information to determine the orientation of the tower, the position of the Vertical Axis Wind Turbine Generator (VAWT) as well as office facade design.

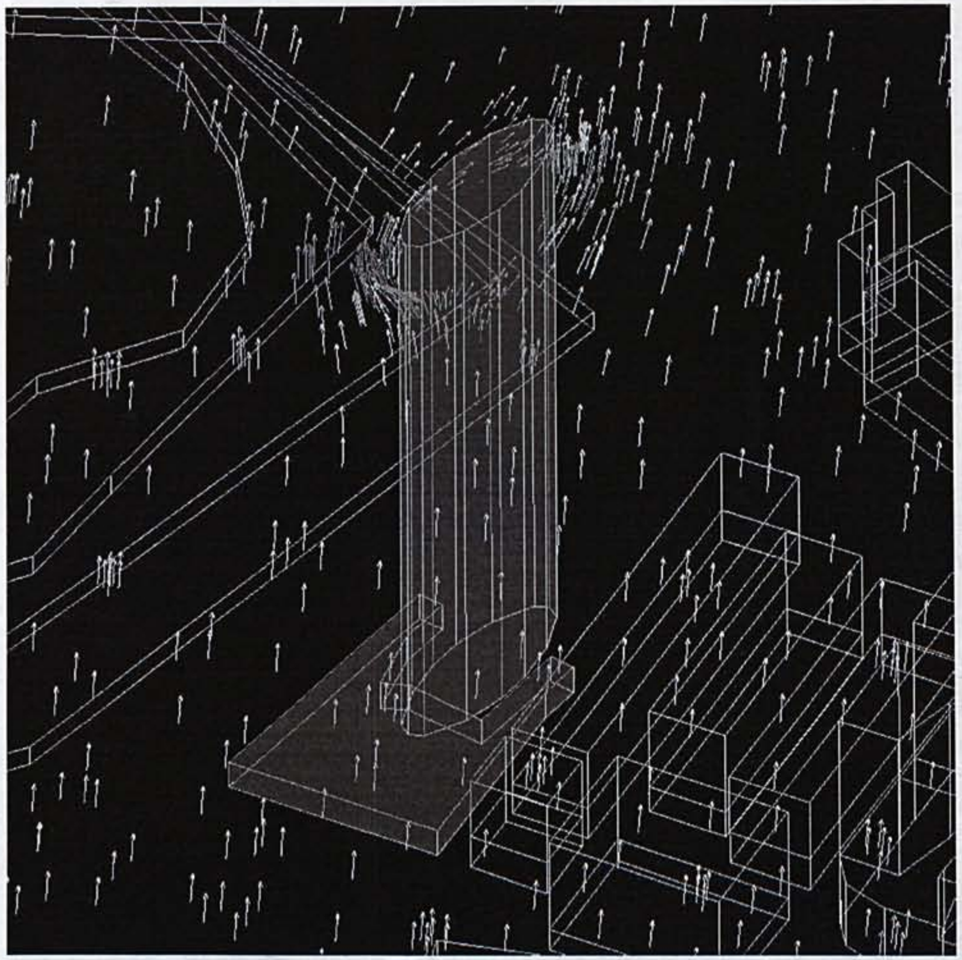
period Ib (October - November)

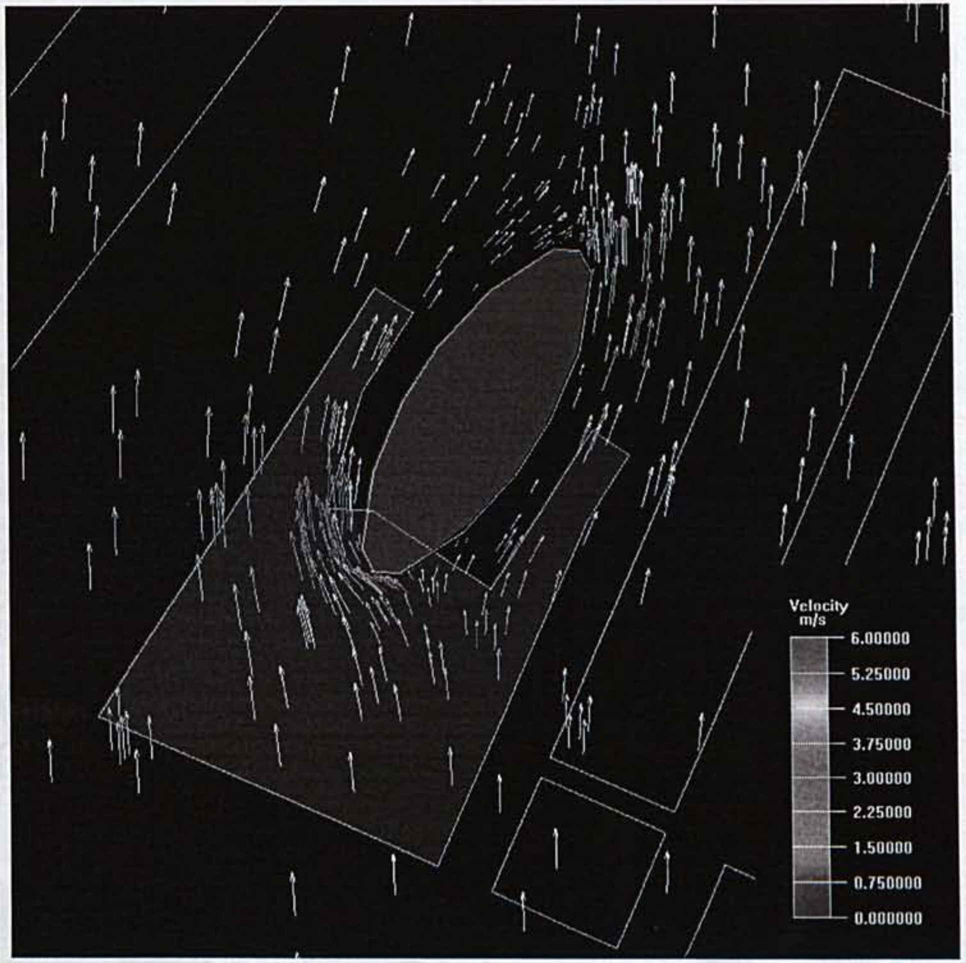
Strategy :
To introduce fresh-air into the interior through the double-skin facade when the weather condition is fine for natural ventilation



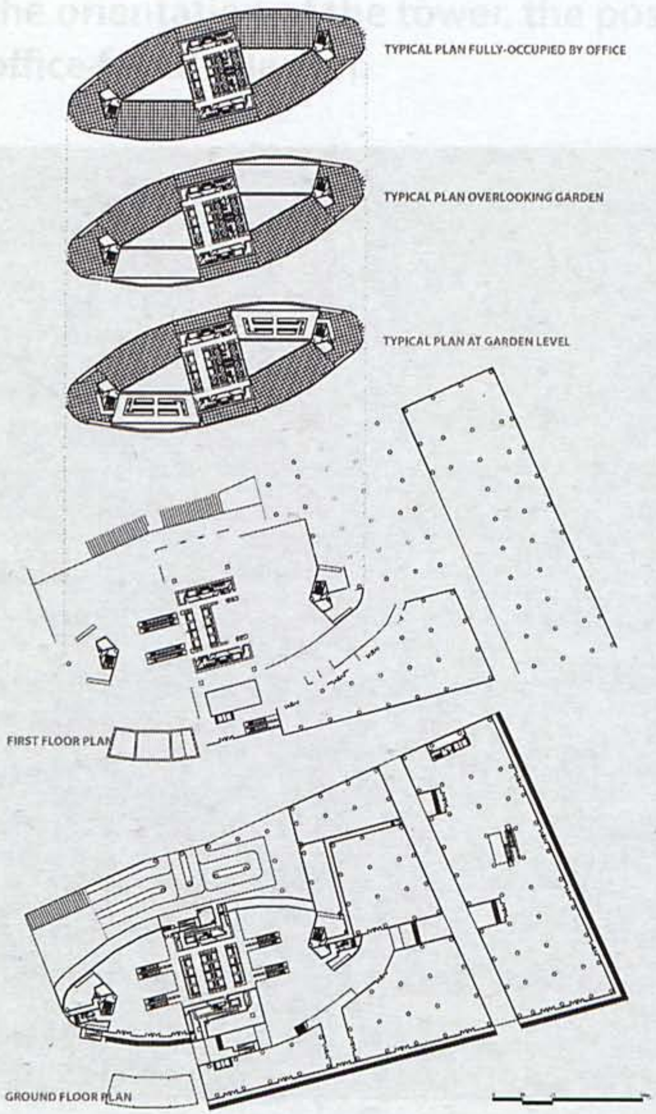
period III (June - August)

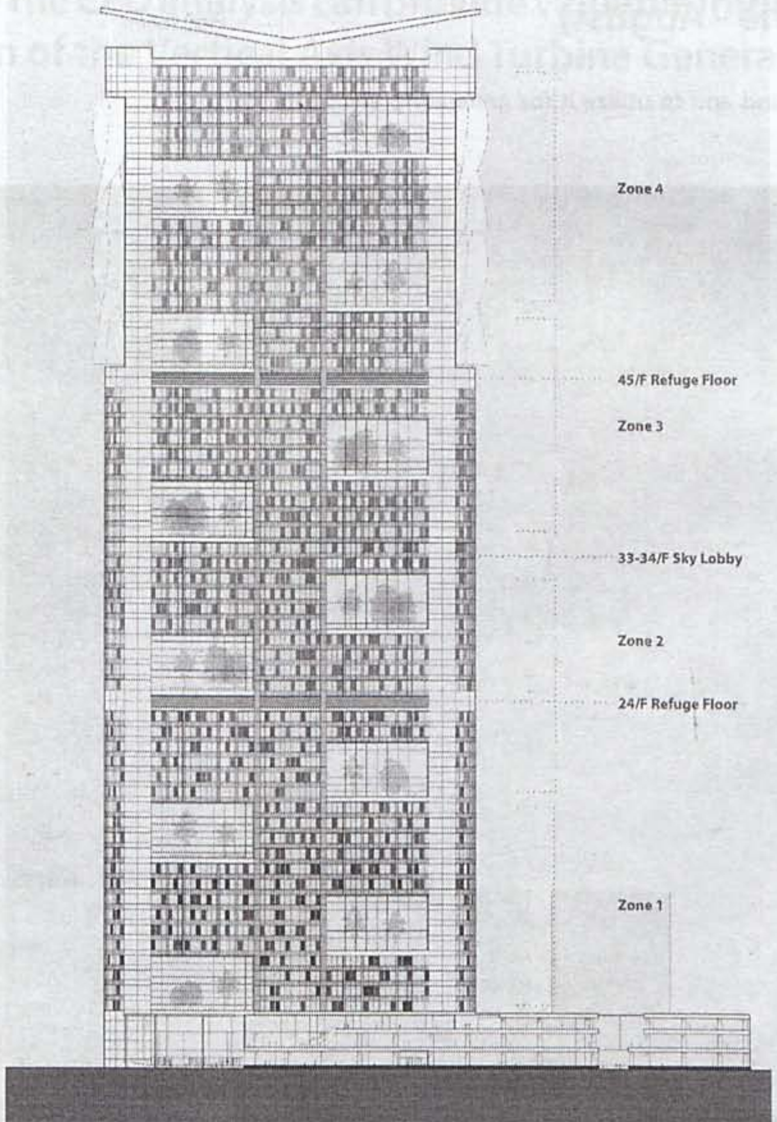
Strategy :
Not to block the prevailing wind and to utilize it for generating electricity for space conditioning;



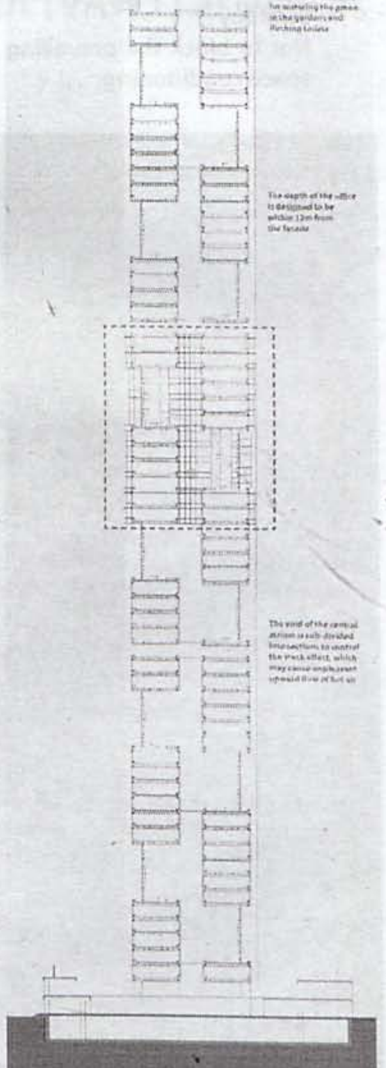


250m



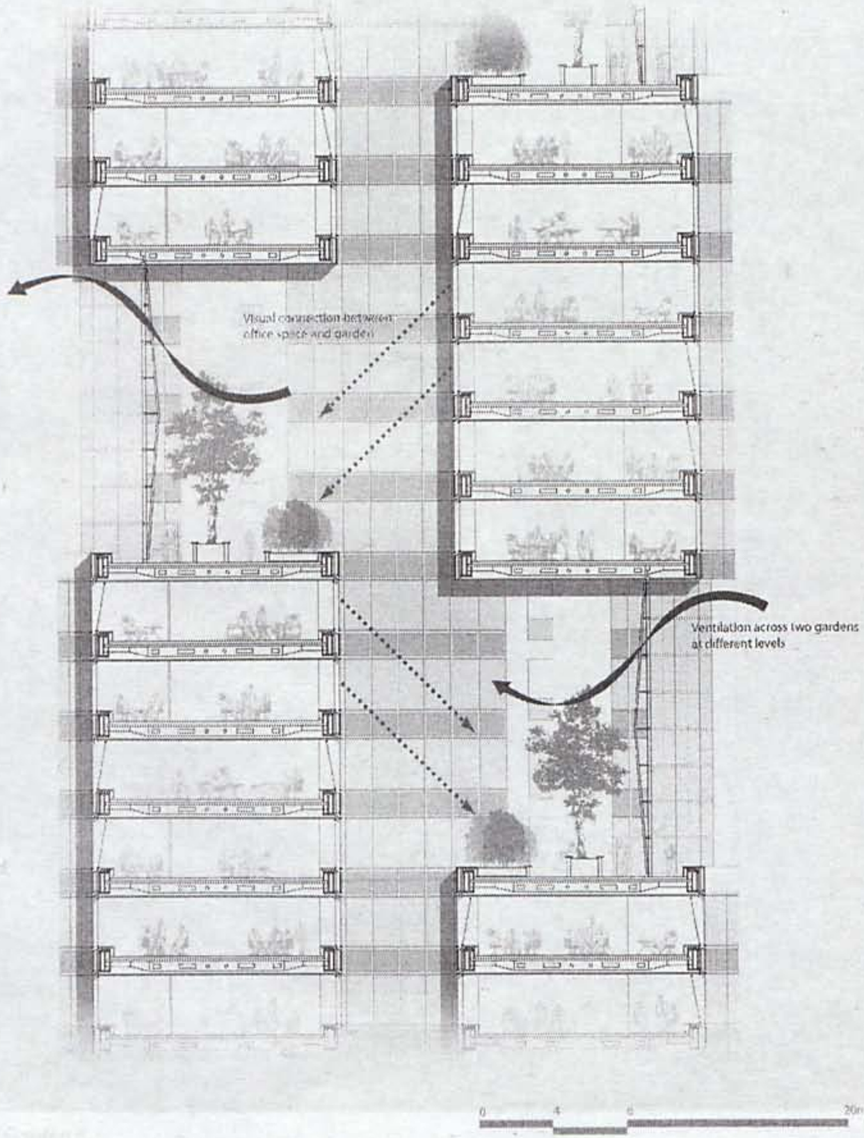


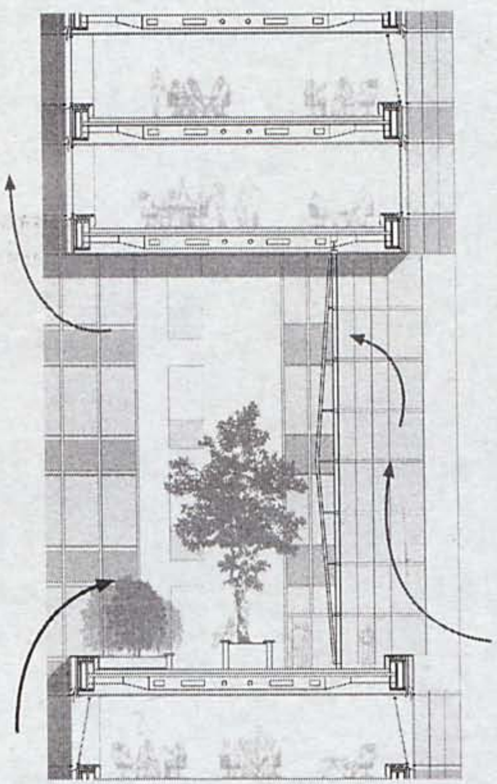
WEST FACADE SHOWING COLOUR PATTERN OF SUN BLINDS



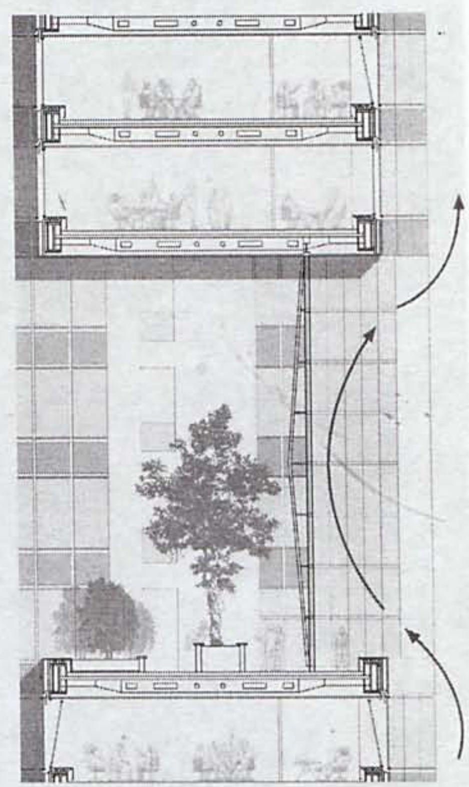
SECTION

SECTION THROUGH GARDENS



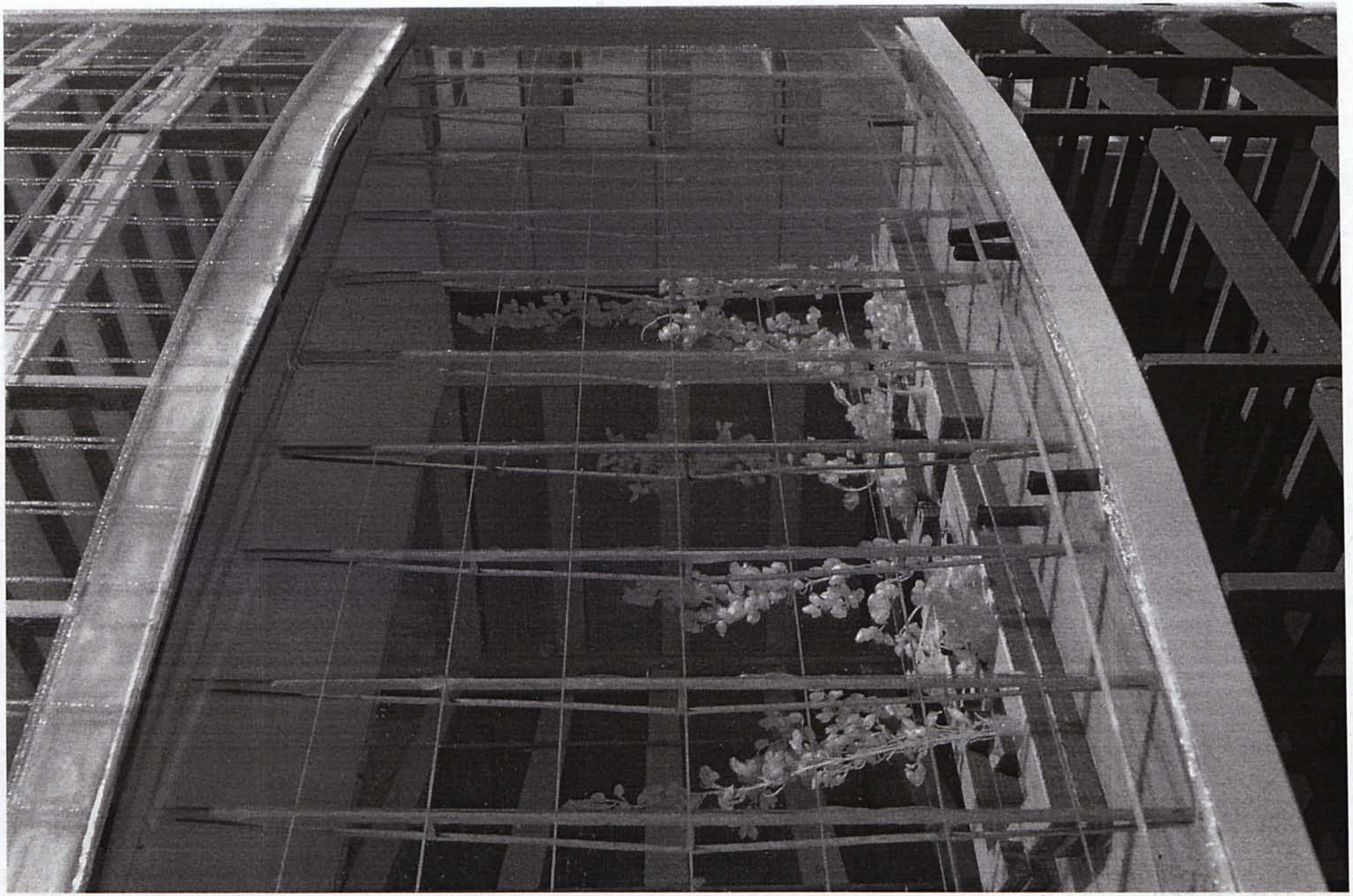


Ventilation Diagram for Day with Fine Weather



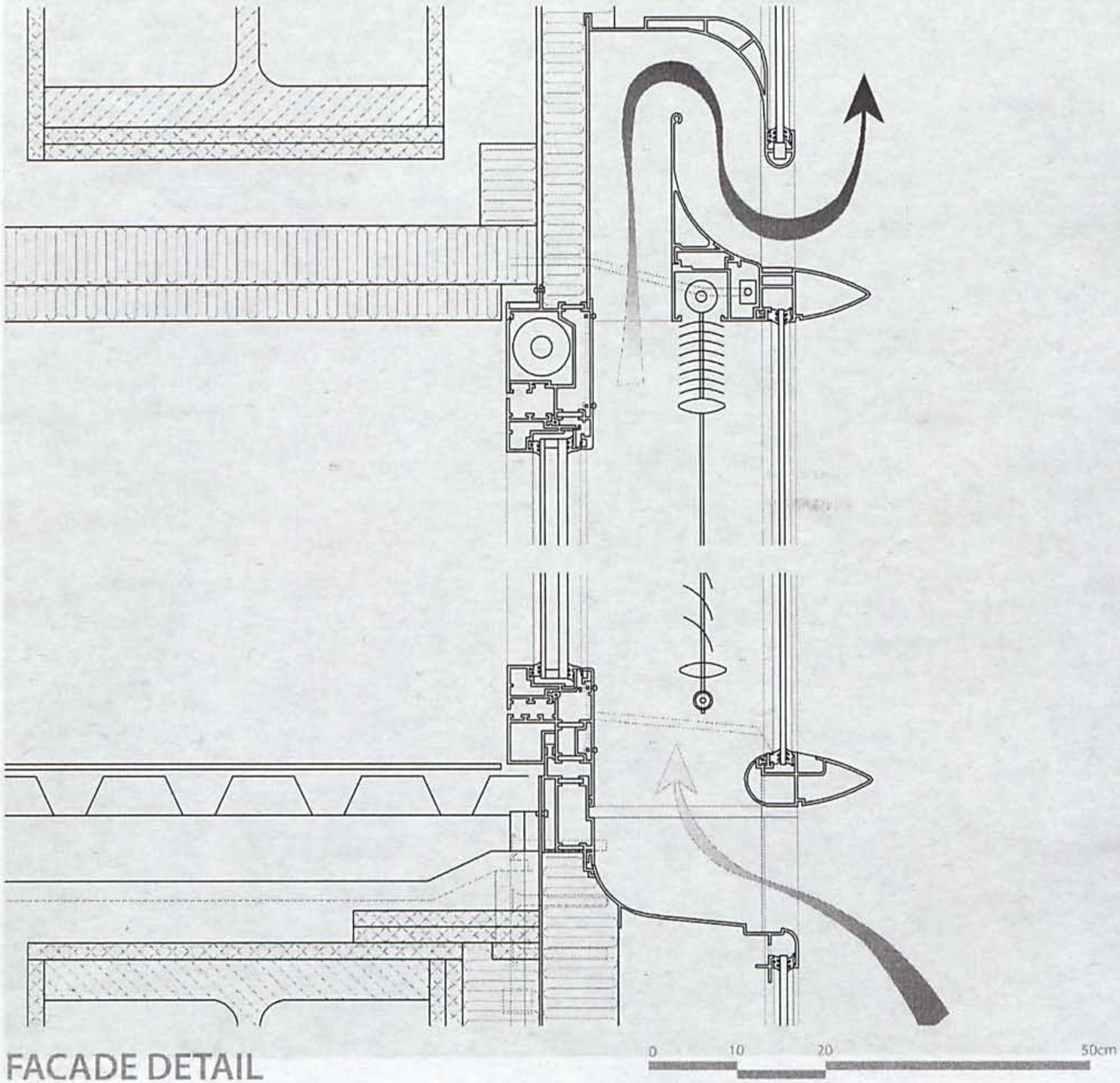
Ventilation Diagram for Day with Bad Weather

View of Garden I

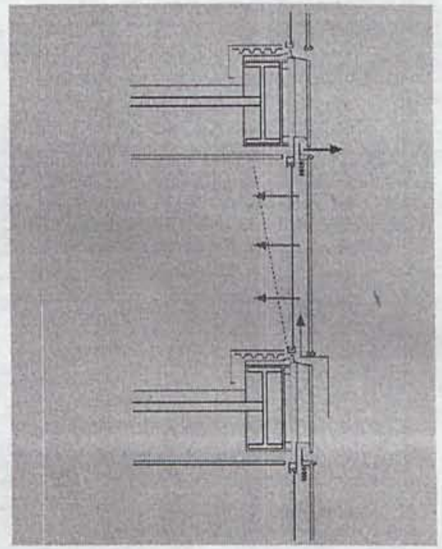


View of Garden II

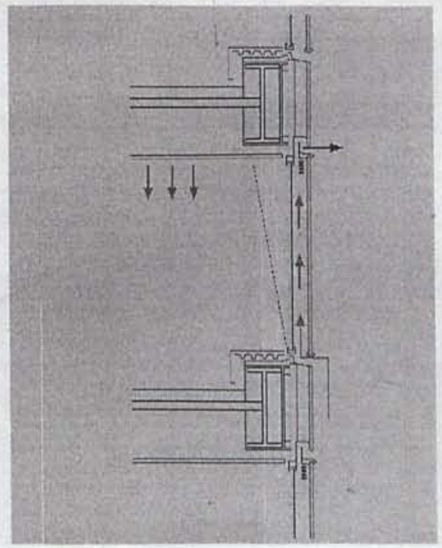
FACADE DESIGN



FACADE DETAIL

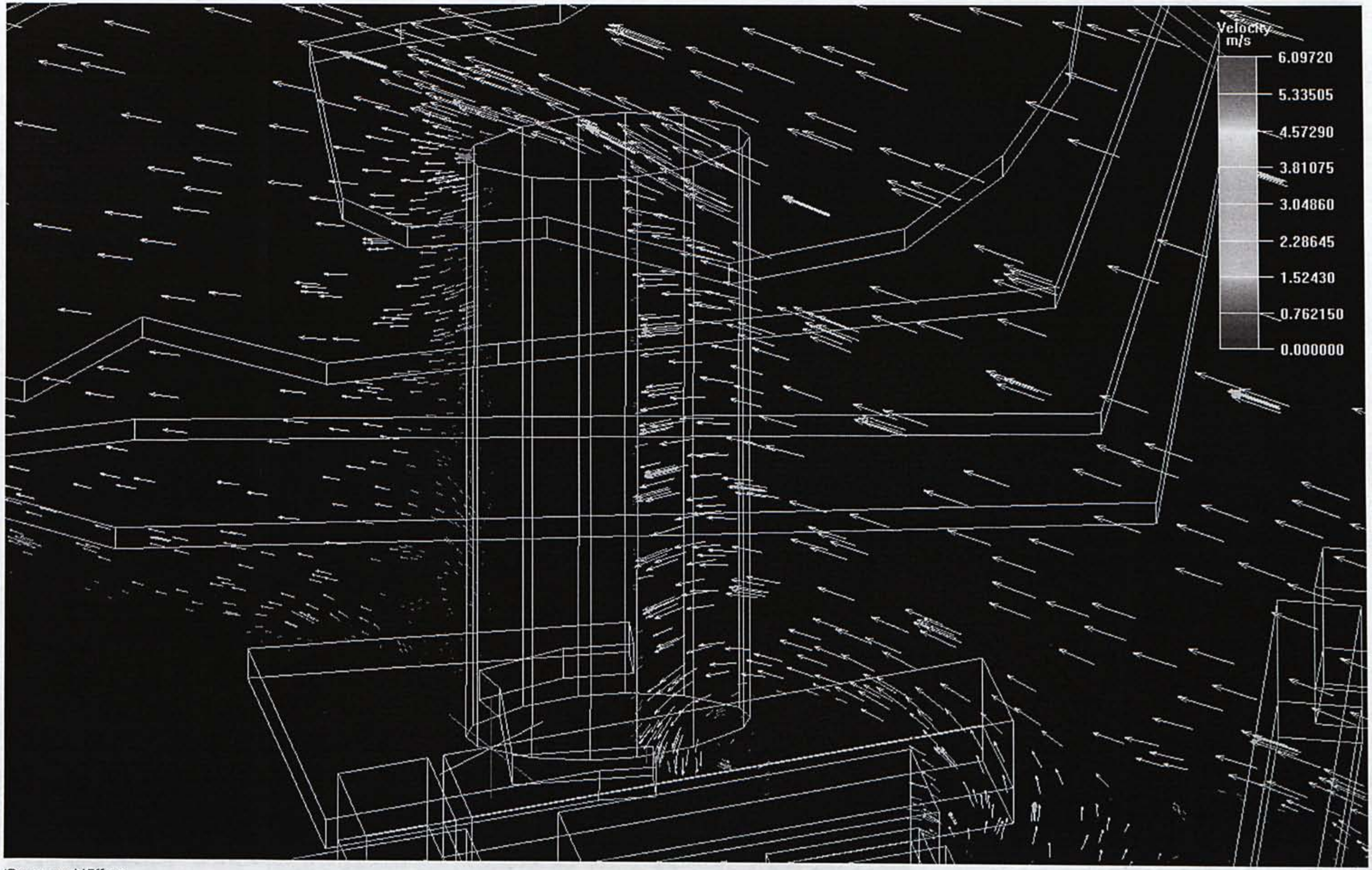


Fresh-air Intake on Day with Fine Weather

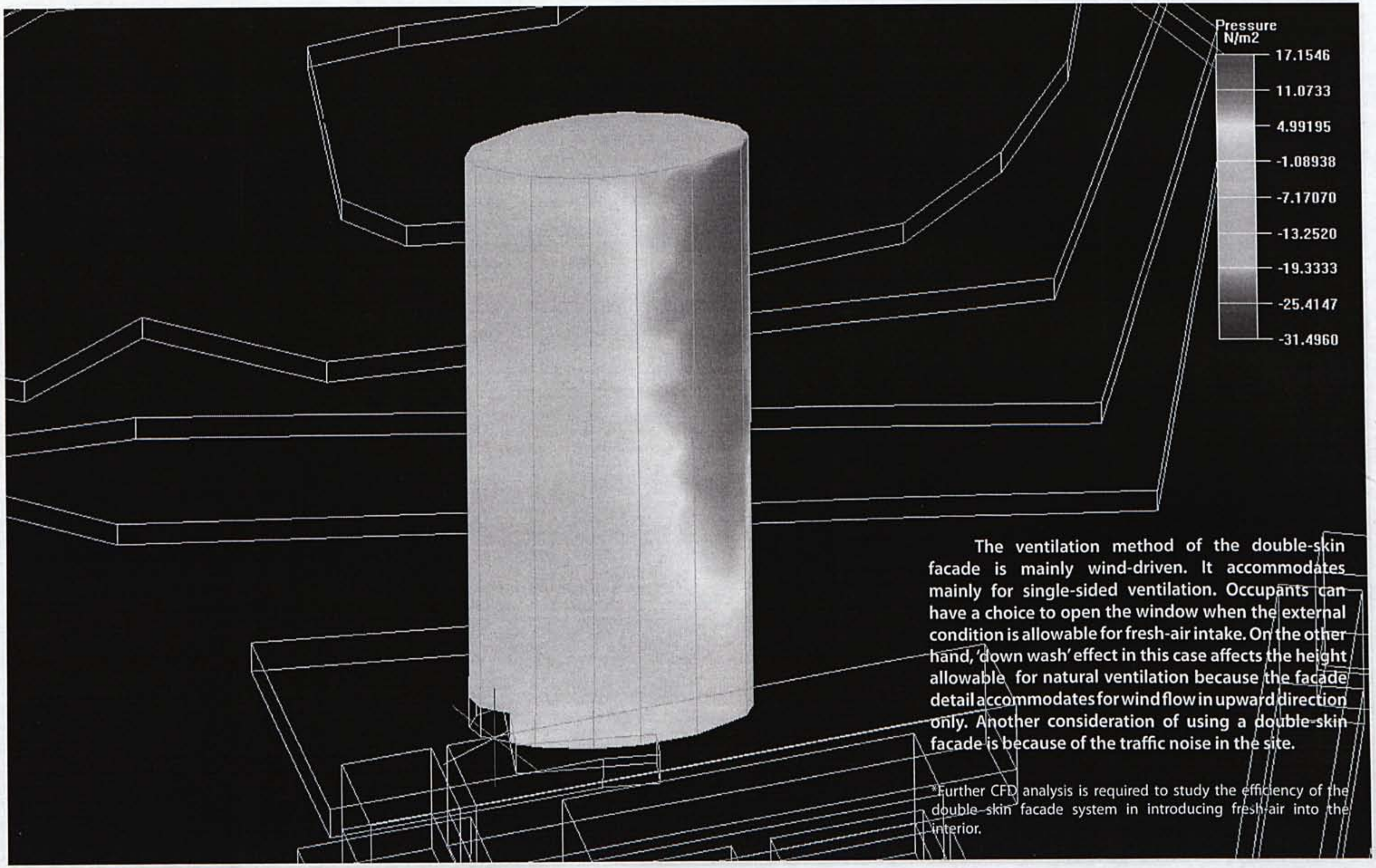


Operation of Cooling Soffit on Hot And Humid Summer's Day

height allowable for natural ventilation



'Down wash' Effect

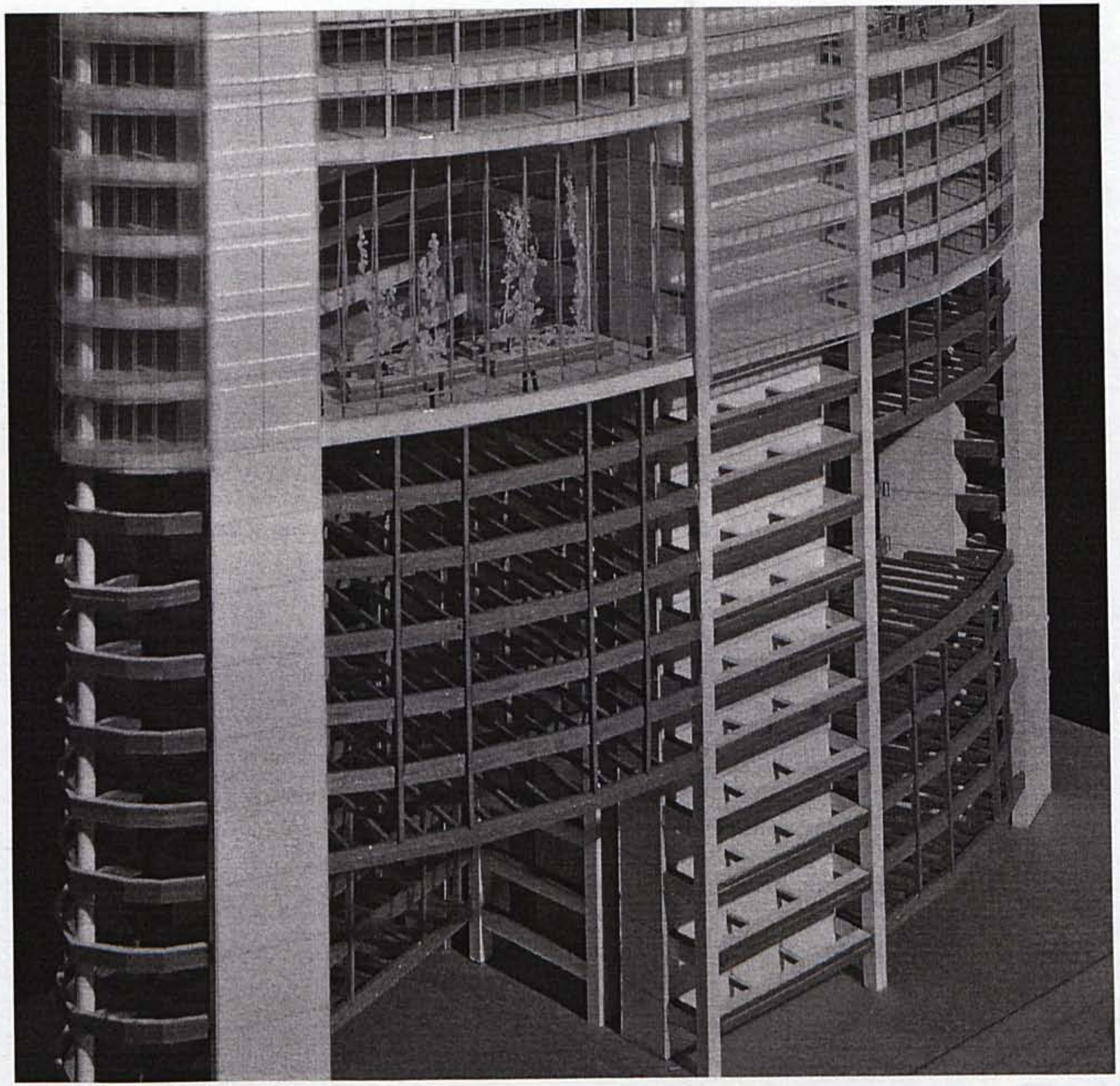


The ventilation method of the double-skin facade is mainly wind-driven. It accommodates mainly for single-sided ventilation. Occupants can have a choice to open the window when the external condition is allowable for fresh-air intake. On the other hand, 'down wash' effect in this case affects the height allowable for natural ventilation because the facade detail accommodates for wind flow in upward direction only. Another consideration of using a double-skin facade is because of the traffic noise in the site.

*Further CFD analysis is required to study the efficiency of the double-skin facade system in introducing fresh-air into the interior.

Pressure Distribution on the Tower's Surface

STRUCTURE



2- to 6-storey high vierendeel truss is used in order to span a maximum distance of 29.5 m across two cores to create a column-free garden